AFFTC-TR-06-06

ARC SEGMENT ATTITUDE REFERENCE (ASAR) HEAD-UP DISPLAY (HUD) SYMBOLOGY AS A PRIMARY FLIGHT REFERENCE TEST AND EVALUATION

A
F
F
T
C

JOSEPH C. JENKINS
Captain, USAF
Project Manager

JANUARY 2008

FINAL REPORT

Approved for public release; distribution is unlimited.

Controlling Office: AFRL/HECV, Wright-Patterson AFB, Ohio 45433-7022.

AIR FORCE FLIGHT TEST CENTER
EDWARDS AIR FORCE BASE, CALIFORNIA
AIR FORCE MATERIEL COMMAND
UNITED STATES AIR FORCE

This technical report (AFFTC-TR-06-06, *Arc Segment Attitude Reference [ASAR] Head-Up Display [HUD] Symbology as a Primary Flight Reference Test and Evaluation*) was submitted under job order number A04HMD00 by the Commander, 412th Test Wing, Edwards AFB, California 93524-6843.

Foreign announcement and dissemination by the Defense Technical Information Center are not authorized because of technology restrictions of the U.S. Export Control Acts as implemented by AFI 16-201.

Prepared by:

Joseph C. Jenkins

JOSEPH C. JENKINS
Captain, USAF
Project Manager

This report has been reviewed and is approved for publication. JAN 2 2 2008

Deborah A. Moisio

DEBORAH A. MOISIO
Chief
Human Systems Integration Flight

O. Carter Wilkinson

O. CARTER WILKINSON
Technical Director
412th Test Wing

Arnold W. Bunch

ARNOLD W. BUNCH, JR.
Colonel, USAF
Commander, 412th Test Wing

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
22-01-2008

2. REPORT TYPE
Final Report

3. DATES COVERED *(From - To)*
07 to 23 July 2004

4. TITLE AND SUBTITLE
Arc Segment Attitude Reference (ASAR) Head-Up Display (HUD) Symbology as a Primary Flight Reference Test and Evaluation

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Jenkins, Joseph C., Captain, USAF, Project Manager

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Air Force Flight Test Center
412th Test Wing
USAF Test Pilot School
220 South Wolfe Avenue
Edwards AFB CA 93524-6485

8. PERFORMING ORGANIZATION REPORT NUMBER
AFFTC-TR-06-06

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory (AFRL/HECV)
2255 H Street
Wright-Patterson AFB OH 45433-7022

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
SC: 012100 CA: Air Force Flight Test Center Edwards AFB CA

14. ABSTRACT
This technical report presents the results of the arc segment attitude reference (ASAR) head-up display (HUD) symbology as a primary flight reference test and evaluation. Testing was requested by the Air Force Research Laboratory, Human Effectiveness Directorate, Wright-Patterson AFB, Ohio. The responsible test organization was the 412th Test Wing, Edwards AFB, California. The test execution organization was the ASAR HUD test team from the USAF Test Pilot School located at Edwards AFB. Testing was performed on the USAF NF-16D Variable-Stability In-Flight Simulator Test Aircraft serial number 86-0048, from 7 to 23 July 2004 and was comprised of 5 ground simulation familiarization and test sessions totaling 12.0 ground test hours, 2 calibration flights and 15 test sorties totaling 23.8 flight test hours. The overall test objective was to determine if the use of the ASAR in the MIL-STD-1787C HUD symbology as the principal attitude reference, in place of the climb-dive ladder, improved pilot performance during unusual attitude recoveries, vertical banked S-turn (S-B) and vertical dive S-turn (S-D) maneuvers, and precision ILS approaches. The vertical S-B maneuver was a continuous series of rate climbs and descents flown on an initial constant heading. The vertical S-D maneuver was similar except that the direction of turn was reversed simultaneously with each change of vertical direction. The overall test objective was met.

15. SUBJECT TERMS
arc segment attitude reference (ASAR)
helmet-mounted display (HMD)
head-up display (HUD)
attitude reference
primary flight reference (PFR)
situation awareness

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON / 19b. TELEPHONE NUMBER *(include area code)*
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAME AS REPORT	70	412 TENG/EN Tech Pubs / 661-277-8615

PREFACE

The author would like to thank Major James Marcolesco and Major Russell Adelgren, USAF Test Pilot School (TPS) staff support; General Dynamics Advanced Information Systems, USAF TPS, Edwards AFB, California, especially Mr. Andy Markofski; 416th Flight Test Squadron, Air Force Flight Test Center (AFFTC), Edwards AFB, California, Mr. John Spravka and Mr. Paul Robinson; 773rd Test Squadron, AFFTC for their outstanding contributions to this effort. The author is also grateful to Lieutenant Colonel Andy Thurling for contributing to the design of the arc segment attitude reference (ASAR) head-up display (HUD) and the F-35 Joint Strike Fighter pilots that served as project pilots for the ASAR HUD flight test: Lieutenant Colonel Norman Eliasen, USMC; Lieutenant Colonel David Sizoo, USAF; Major Michael Legens, USMC; Lieutenant Commander Todd Huber, USN; and Mr. David Nelson, Lockheed Martin Aeronautics.

This page intentionally left blank.

EXECUTIVE SUMMARY

This technical report presents the results of the arc segment attitude reference (ASAR) head-up display (HUD) symbology as part of a primary flight reference test and evaluation. Testing was requested by the Air Force Research Laboratory, Human Effectiveness Directorate, Wright-Patterson AFB, Ohio. The responsible test organization was the 412th Test Wing, Edwards AFB, Californa. The test execution organization was the ASAR HUD test team from the USAF Test Pilot School (TPS), Edwards AFB. Testing was performed on the USAF NF-16D Variable-Stability In-Flight Simulator Test Aircraft (VISTA) from 7 to 23 July 2004 and was comprised of 5 ground simulation familiarization and test sessions totaling 12.0 ground test hours, 2 calibration flights and 15 test sorties totaling 23.8 flight test hours.

The ASAR HUD utilized all the symbology found in the MIL-STD-1787C HUD format with the exception of the climb-dive ladder attitude reference. The ASAR was incorporated into the MIL-STD-1787C HUD format in place of the climb-dive ladder as the principal on-boresight attitude reference. This evaluation examined three symbology formats: the MIL-STD-1787C HUD, the dual-articulated (DA) HUD, and the MIL-STD-1787C with ASAR symbology.

The overall test objective was to determine if the use of the ASAR in the MIL-STD-1787C HUD symbology in place of the climb-dive ladder as the principal attitude reference improved pilot performance when completing unusual attitude recoveries (UARs), vertical banked S-turn (S-B) and vertical dive S-turn (S-D) maneuvers, and precision ILS approaches. The overall test objective was met.

Pilot reaction time completing UARs using the ASAR HUD was statistically significantly faster than when using the MIL-STD-1787C HUD. However, it was not significantly different for the ASAR HUD in comparison with the DA HUD. All three HUD formats were satisfactory for performing vertical S-B and vertical S-D maneuvers, and ILS approaches. However, the ASAR HUD was the format most preferred for completion of nose-low UARs. Pilots noted that more precise attitude information near the horizon was needed. Mechanizing the ASAR to provide more detailed attitude information when within ±10 degrees of the horizon will provide the necessary precision. The ASAR was used with navigational ILS symbology, but has yet to have any developmental flight testing done with mission/tactical symbology.

This page intentionally left blank.

TABLE OF CONTENTS

Page No.

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Concluded)

LIST OF TABLES

INTRODUCTION

This technical report presents the results of the arc segment attitude reference (ASAR) head-up display (HUD) symbology as a primary flight reference (PFR) test and evaluation. Testing was requested by the Air Force Research Laboratory (AFRL), Human Effectiveness Directorate, Wright-Patterson AFB, Ohio. The responsible test organization was the 412th Test Wing, Edwards AFB, California. The test execution organization was the ASAR HUD test team from the USAF Test Pilot School, Edwards AFB. Testing was performed on the USAF NF-16D Variable-Stability In-Flight Simulator Test Aircraft (VISTA), serial number 86-0048 from 7 to 23 July 2004 and comprised of 5 ground simulation familiarization and test sessions totaling 12.0 ground test hours, 2 calibration flights and 15 test sorties totaling 23.8 flight test hours.

The VISTA data acquisition system was used to record aircraft data, and pilots provided ratings and comments. General Dynamics Advanced Information Systems group performed all specialty engineering. Ground testing and calibration flights were accomplished prior to flight test to ensure that the VISTA Simulation System (VSS) was correctly programmed and functional. A description of the VISTA aircraft and the VISTA display system are presented in appendix A.

The ASAR HUD was compared to the MIL-STD-1787C HUD symbology, Department of Defense Interface Standard, *Aircraft Display Symbology* (reference 1), which was used as a baseline symbology, and to the dual-articulated (DA) MIL-STD-1787C HUD. The three test symbology configurations were evaluated during both ground and flight tests.

BACKGROUND

The AFRL designed the ASAR as an on-boresight HUD attitude reference to be used with the MIL-STD-1787C HUD symbol set in place of the climb-dive ladder as the principal attitude reference in a helmet-mounted display (HMD). The goal was to develop an attitude reference for on-boresight use that was compatible with off-boresight HMD attitude references such as the Advanced Non-Distributed Flight Reference (ANDFR) symbology, while retaining as much of the MIL-STD-1787C symbology as possible.

The ASAR concept was first developed by Dornier in 1987 as a replacement for the HUD climb-dive ladder (Advisory Group for Aerospace Research and Development [AGARD]-CP-520, “Symbology for Head-Up and Head-Down Applications for Highly Agile Fighter Aircraft – to Improve Spatial Awareness” [reference 2]). This initial design was the precursor to the AFRL ASAR. The Dornier symbology was informally named the Orange Peel by German Air Force pilots who used it first (figure 1). At straight and level flight, a 180-degree attitude arc was presented below the aircraft symbol. During a climb, the attitude arc shortened to indicate increasing climb angles until, at 90-degree climb, only the Orange Peel gap marks remained. Dive angles were indicated by increasing the amount of attitude arc displayed, eventually forming a complete circle. Bank angles were determined by comparing the rotation of the arc to the vertical axis of the aircraft symbol.

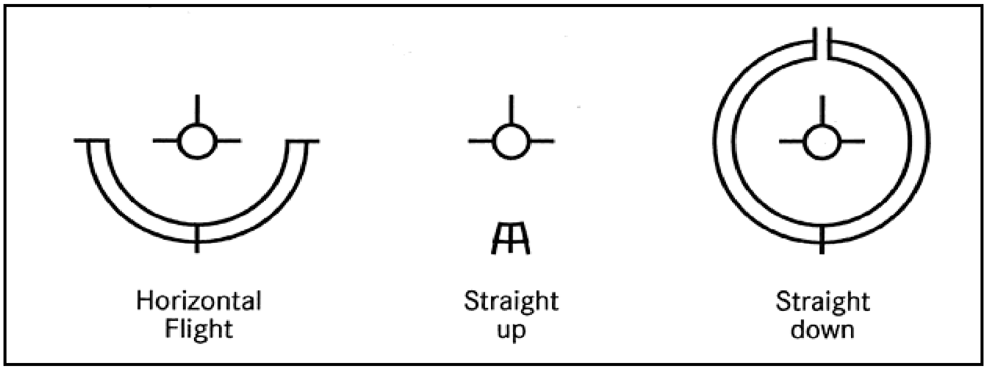


Figure 1 Orange Peel Head-Up Display Symbology Circa 1987

The ASAR symbology modification was based on pilot recommendations, flight tests, and simulator data (AGARD-CP-577, "Arc Segment Altitude Reference – ASAR" [reference 3]). The modified version included dots and gaps in the arc, displayed at ±30 degrees and ±60 degrees of climb-dive, to convey a more precise representation of climb-dive attitudes and bank. Once the dots were passed, gaps replaced the dots. The reverse was used to represent climb angles. Initially, gaps were shown in the 180-degree attitude arc below the aircraft symbol representing ±30 and ±60 degrees of climb. As these were passed, the dots appeared (figure 2). Later modifications included a fixed dash mark at the bottom of the circle as a roll reference, a triangle serving as a ground pointer, and dots were changed to diamonds. The final version of the ASAR is shown in figure 3.

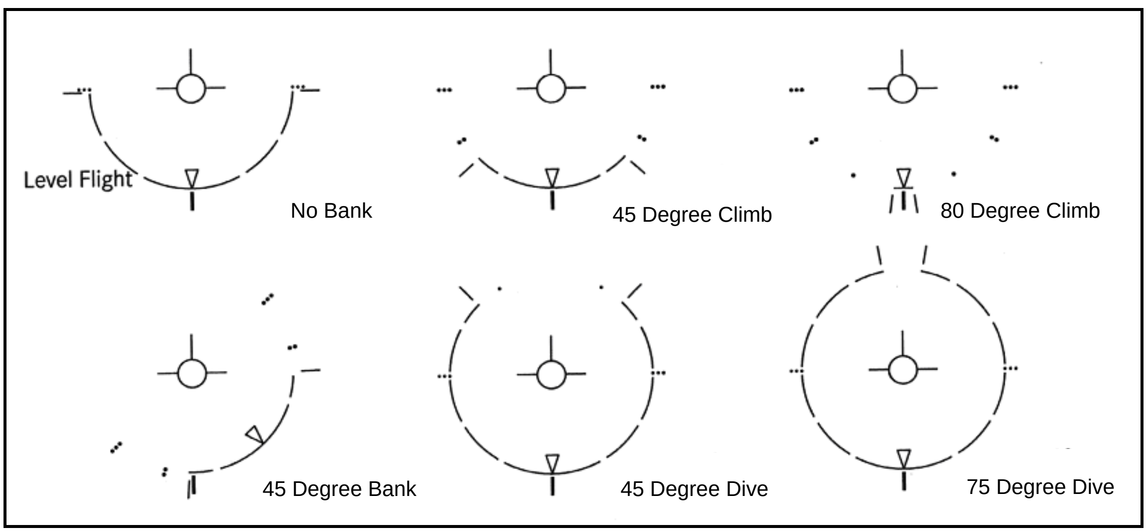


Figure 2 Arc Segment Attitude Reference Symbology with 'Dots' and Gaps For 0, ± 30, and ± 60 Degrees

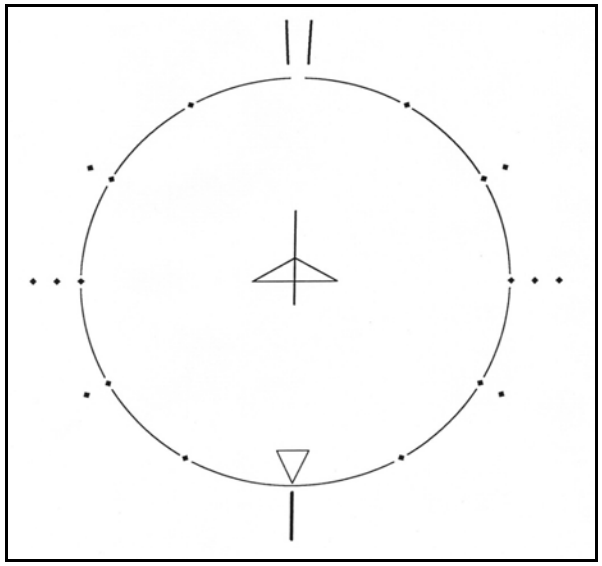


Figure 3 Final Version of the Arc Segmented Attitude Reference Symbology with ‘Diamonds’ and Gaps For 0, ± 30, and ± 60 Degrees

An earlier flight test evaluation indicated that the ASAR could accurately convey attitude information to the pilot during UARs, resulting in quick recoveries with less workload than that using the climb-dive ladder (reference 2). This finding was augmented by a simulation trial that compared the ASAR to the HUD climb-dive ladder with the result that UARs were accomplished 30 percent faster (reference 3). In addition, when compared to the climb-dive ladder, the ASAR was rated as superior when used with air-to-air symbology, better than or equal to when used with air-to-ground symbology, and better than or equal to during basic instrument flying (with the addition of climb-dive bars at +10 degrees and -40 degrees). Because the ASAR was a compressed flight reference, which was necessary to present the entire aircraft maneuvering envelope, its ability to convey precise climb-dive angles near the horizon was limited. However, the overall performance of the ASAR was such that it was included in the display suite for the Eurofighter 2000, i.e., Typhoon, as a HUD attitude reference.

TEST ITEM DESCRIPTION

ASAR HUD Symbology:

The test item was the ASAR symbology format. Head-up display symbology for the three test sets was identical except for the attitude reference. The ASAR HUD format was identical to that of the MIL-STD-1787C HUD (figure 4) format with the exception of the replacement of the climb-dive ladder with the ASAR as the principal on-axis attitude reference. The climb/dive marker (CDM) and ASAR were mechanized to operate in the ‘caged mode,’ meaning they were locked to the center of the HUD field of view (reference 1). This was done to account for excessive crosswind or sideslip causing a large drift angle. Caging was similar to the drift cutout mode used in the F-15 and F-16 aircraft, which stabilized symbology on the HUD lateral centerline axis. The CDM was allowed to translate up and down but not allowed to drift left or right in the display. The HUD flightpath marker (FPM) was still free to travel throughout the display field of view and remained the conformal representation of the velocity vector of the aircraft. The HUD CDM remained partially conformal for elevation (up and down) but not azimuth (left or right). That is, the CDM was not wind corrected. The placement of the ASAR relative to that of the CDM was held constant on the display. In straight and level flight, the ASAR formed a half circle and the three diamonds representing 0-degree climb-dive at the end points of the ASAR were level with the CDM.

A Ghost FPM was used in combination with the CDM to provide wind-corrected flight path angle. The CDM used numerals, placed on the left side of the climb-dive ladder lines, to depict the climb-dive readout; the ASAR HUD used a digital climb-dive readout located immediately below the CDM. This readout, like the ASAR itself, traveled along with the CDM during commanded attitudes (figure 5).

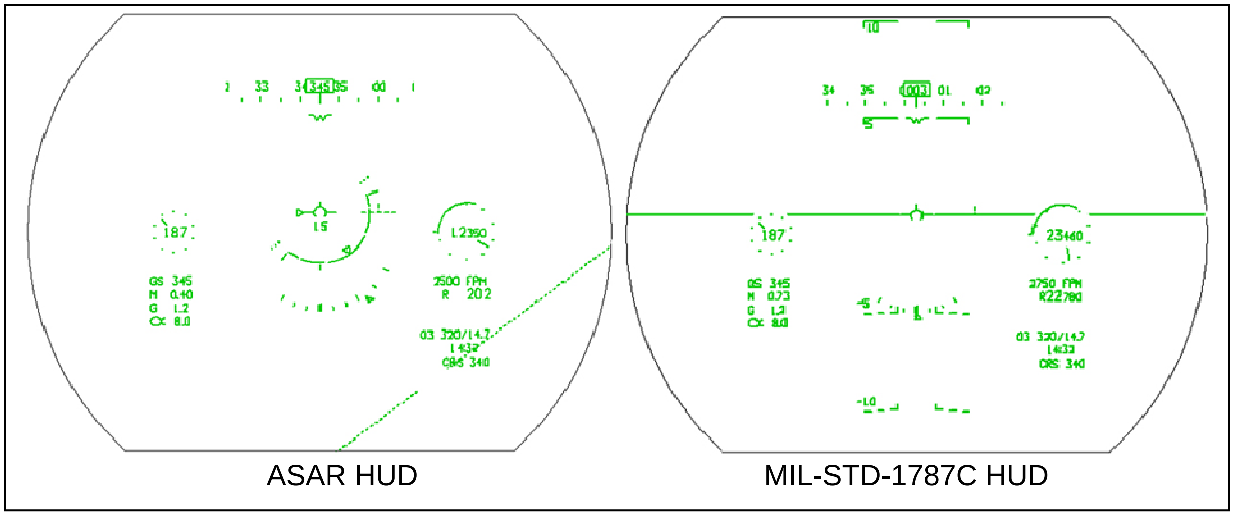


Figure 4 Comparison of Arc Segment Attitude Reference (ASAR) and MIL-STD-1787C Head-Up Display (HUD) Symbology

During straight and level flight, the visible lower half of the ASAR represented the area below the horizon. As the climb angle increased, the ASAR began to narrow in proportion to the climb angle (figure 5). Conversely, with an increase in dive angle, the ASAR closed to form a more complete circle (figure 6).

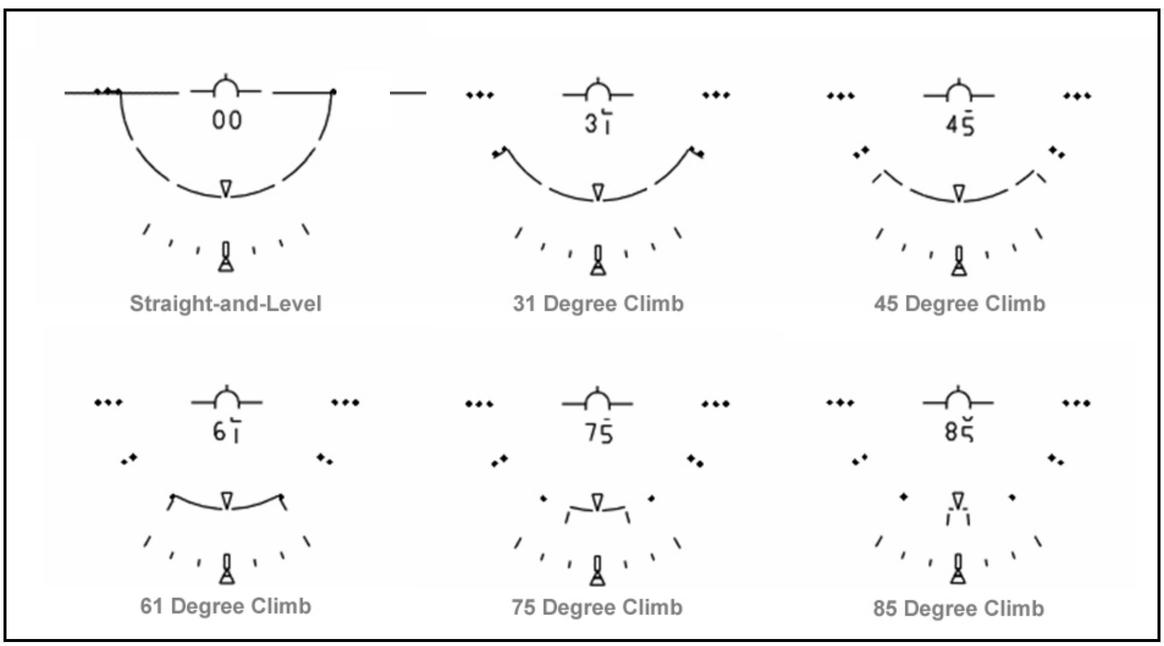


Figure 5 Arc Segment Attitude Reference Head-Up Display Climb Attitudes

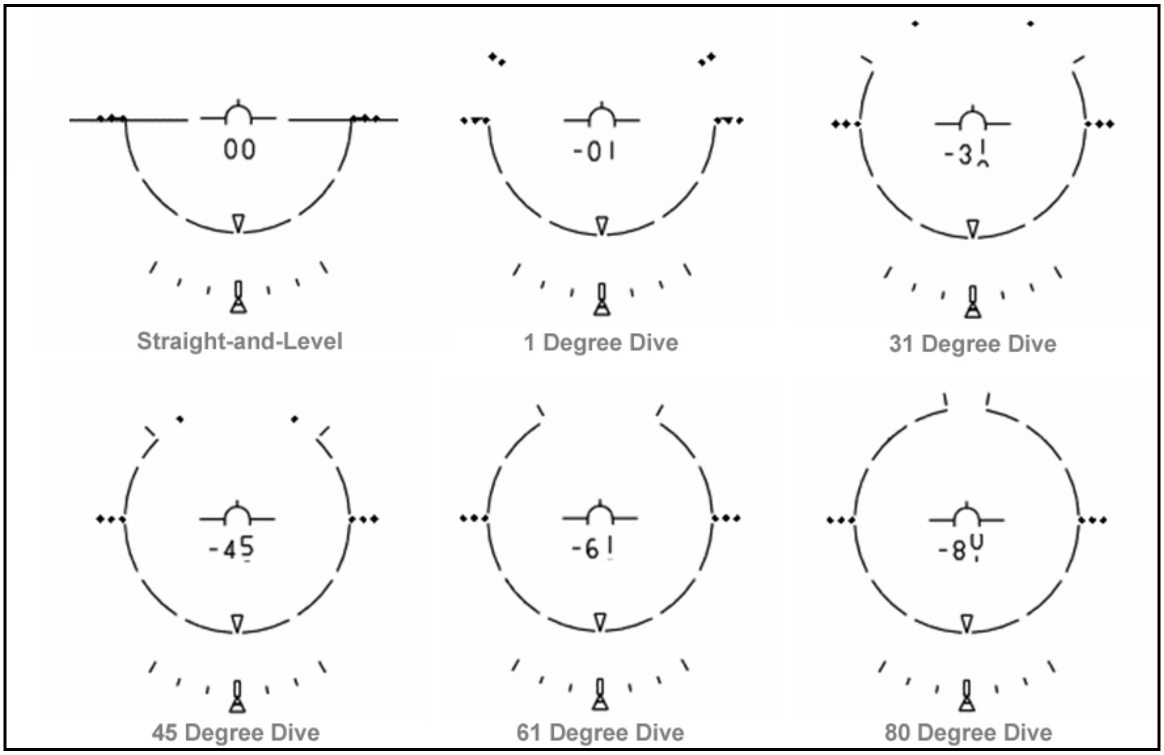


Figure 6 Arc Segment Attitude Reference Head-Up Display Dive Attitudes

The ASAR displayed diamonds and gaps at ±30 degrees and ±60 degrees of climb-dive. For climb angles, gaps were initially shown in the ASAR at straight-and-level flight representing +30 and +60 degrees of climb. As the 30 and 60 degree climb angles were passed, the diamonds replaced the gaps. As the 30 and 60 degree dive angles were passed, the gaps replaced the diamonds. At the bottom of the ASAR circle, a triangle was displayed that served as a ground pointer and an additional roll reference that could be utilized for angle-of-bank (AOB) (figure 7).

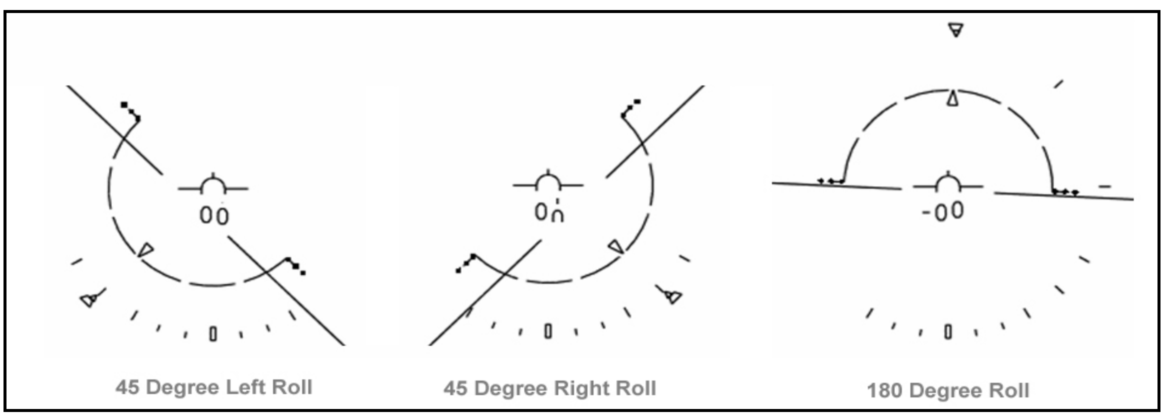


Figure 7 Arc Segment Attitude Reference Head-Up Display Roll Attitudes

Dual-Articulated MIL-STD-1787C HUD Symbology:

Unlike most HUD climb-dive ladder formats, the ladder of the DA MIL-STD-1787C HUD was mechanized to articulate or bend in toward the horizon line at half the actual climb angle displayed for both climb and dive (figure 8). For example, for a 20-degree climb the bars articulated 10 degrees toward the HUD horizon line. Because of this articulation or bending, the ladder bars were sometimes called “bendy bars.” This dual articulation was the same climb-dive ladder mechanization used on F-18 and F-15E HUDs. Also, the DA HUD horizon pointing tags were moved to the inside of the ladder. This was opposite of the MIL-STD-1787C HUD, which positioned them on the outside of the ladder as a directional cue to the nearest horizon. Aside from these two differences, the DA HUD format was the same with respect to ownship status symbology as that of the MIL-STD-1787C HUD.

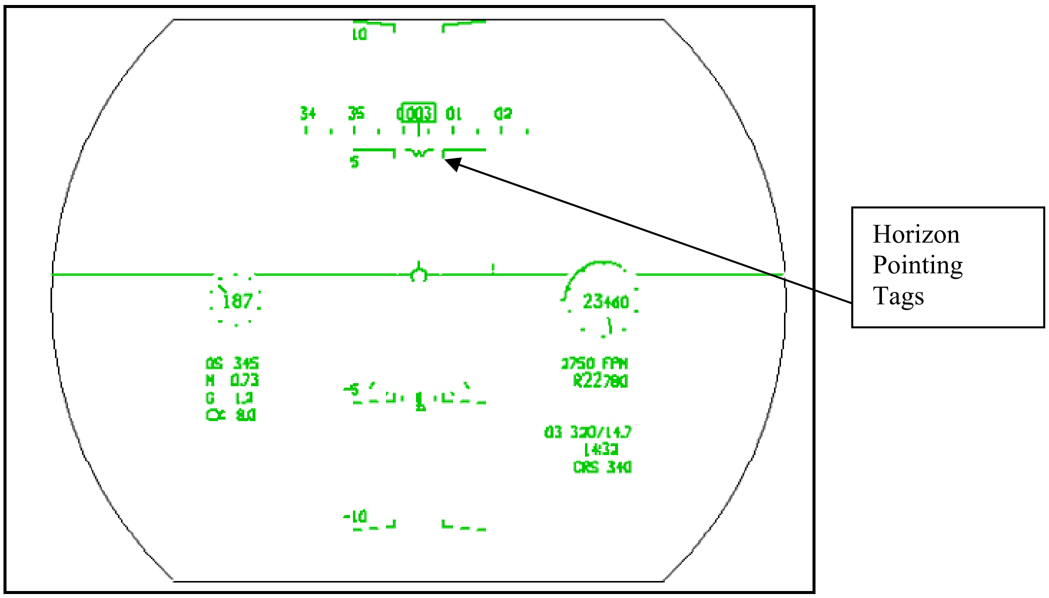


Figure 8 Dual Articulated MIL-STD-1787C Head-Up Display Symbology

MIL-STD-1787C HUD Symbology:

The MIL-STD-1787C HUD symbology was the HUD format endorsed by the Air Force Flight Standards Agency as a PFR for use in USAF aircraft. This endorsement was granted following a series of simulation and flight test evaluations conducted from 1990 to 1992, and provided the basis for the current F-22A HUD and F-35 Joint Strike Fighter virtual HUD symbology formats. In this test, the MIL-STD-1787C HUD symbology served as the baseline measure of performance to compare with the alternate HUD symbology sets (reference 1). This baseline symbology included a climb-dive ladder and FPM for ownship attitude reference, an airspeed indicator, an altimeter, and a heading tape. Both the airspeed indicator and altimeter used a digital readout with a dial and counter pointer (figure 9).

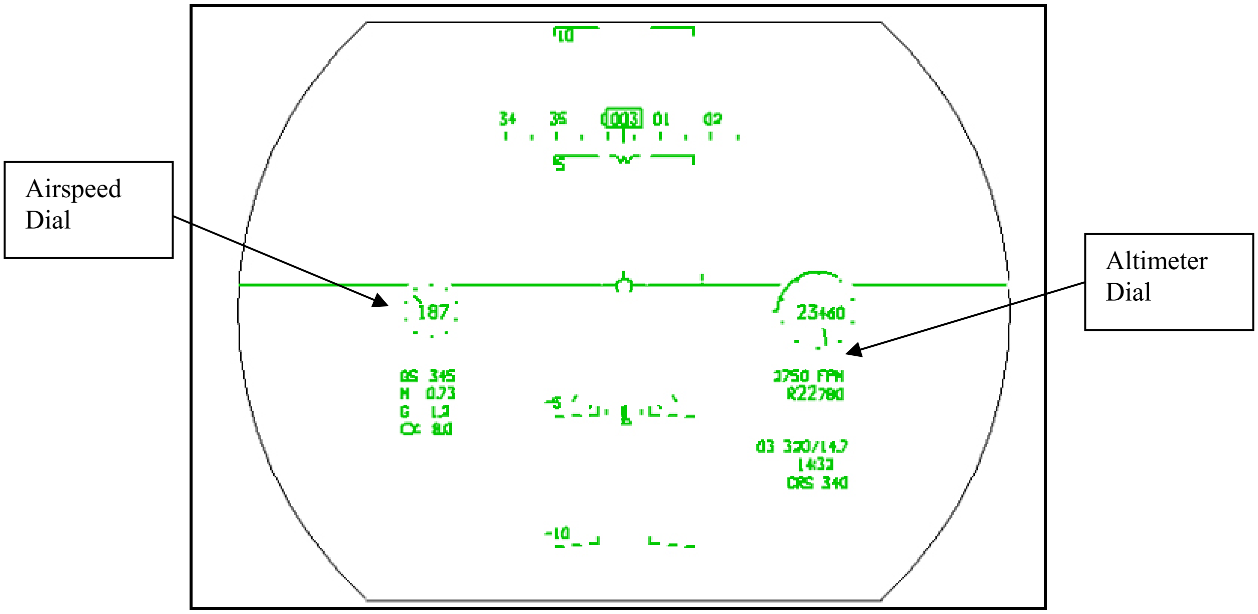


Figure 9 MIL-STD-1787C Head-Up Display Symbology

OVERALL TEST OBJECTIVE

The overall test objective was to determine if the use of the ASAR in the MIL-STD-1787C HUD symbology set, in place of the climb-dive ladder as the principal attitude reference, improved pilot performance for UARs, vertical banked S-turns (S-B) and vertical dive S-turn (S-D) maneuvers, and precision ILS approaches. The overall test objective was met.

This page intentionally left blank.

TEST AND EVALUATION

GENERAL

A build-up approach was used to evaluate each configuration during this test. First, vertical S-B and vertical S-D maneuvers were flown, followed by ILS precision approaches, and finally UARs. The vertical S-B maneuver was a continuous series of rate climbs and descents flown on a constant heading. The vertical S-D maneuver was the same as the vertical S-B, except that the direction of turn was reversed simultaneously with each change of vertical direction. Pilot workload ratings using the Modified Cooper-Harper (MCH) rating scale, figure B1 ("A Validated Rating Scale for Global Mental Workload Measurement Applications" [reference 4]), and situation awareness ratings using the China Lake Situation Awareness (CLSA) rating scale, ("Practical Considerations for Measuring Situational Awareness" [reference 5]) table B1, were collected for each symbol set following task completion. Task criteria for each of the piloting tasks was specified in Air Force Manual (AFM) 11-217, *Instrument Flight Procedures*, (reference 6). The intent was to isolate differences in pilot task performance due to differences in the HUD attitude symbology.

Both ground and flight tests were accomplished to determine if the ASAR HUD improved pilot performance. The VISTA ground flight-simulation mode was used to familiarize pilots with the HUD symbology, and to collect baseline data for the simulated vertical S-B, vertical S-D maneuvers, ILS approaches, and UARs. Test flights were then flown to assess the HUD formats during the actual maneuvers.

During ground and flight testing, a vision restriction device (VRD) was used to eliminate the view of the real horizon and simulate a night/weather unusual attitude (figure 10). The VRD consisted of three key elements: a blue translucent vinyl canopy covering, a USAF high-contrast amber visor, and a visor cover with cutouts that allowed only the HUD to be viewed. The pilot could see outside the cockpit through either the blue vinyl canopy covering or the amber visor of the VRD (figure 11), but not when both were combined. When combined, the amber helmet visor and blue vinyl blocked out all outside visual input and produced a black background that simulated IMC flying conditions with no discernable horizon (figure 12). The visor cover with masking was used since the forward half of the canopy covered by the blue vinyl had to be scaled back to allow the safety pilot (SP) to visually acquire the runway during ILS approaches (figure 13). The VRD was used throughout ground and flight testing to reduce distractions and minimize access to the natural horizon, thereby placing complete dependence on the HUD symbology for performing the tasks.

Figure 10 Vision Restriction Device for Ground and Flight Unusual Attitude Recovery

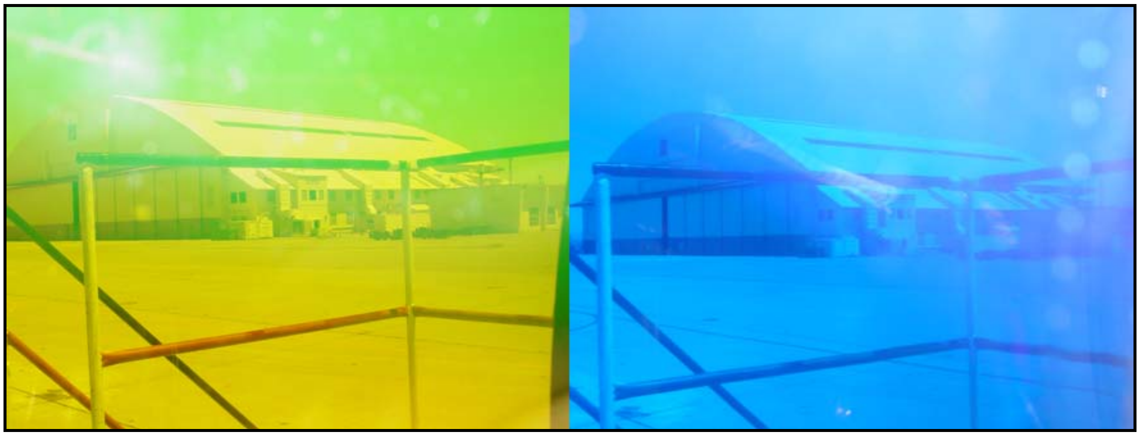


Figure 11 Amber Visor View (Left)/Blue Vinyl View (Right) with Canopy Down

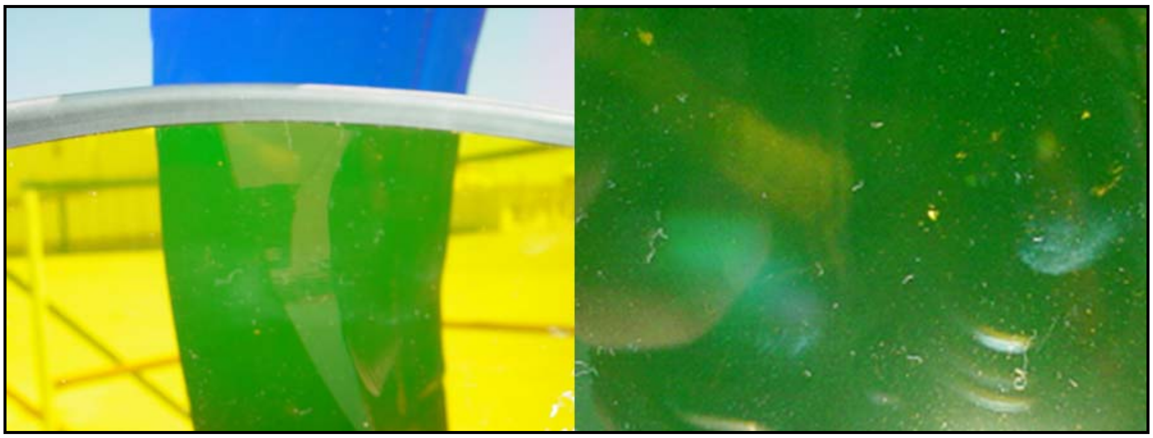


Figure 12 Amber Visor Combined with Blue Vinyl on Canopy to form the Vision Restriction Device

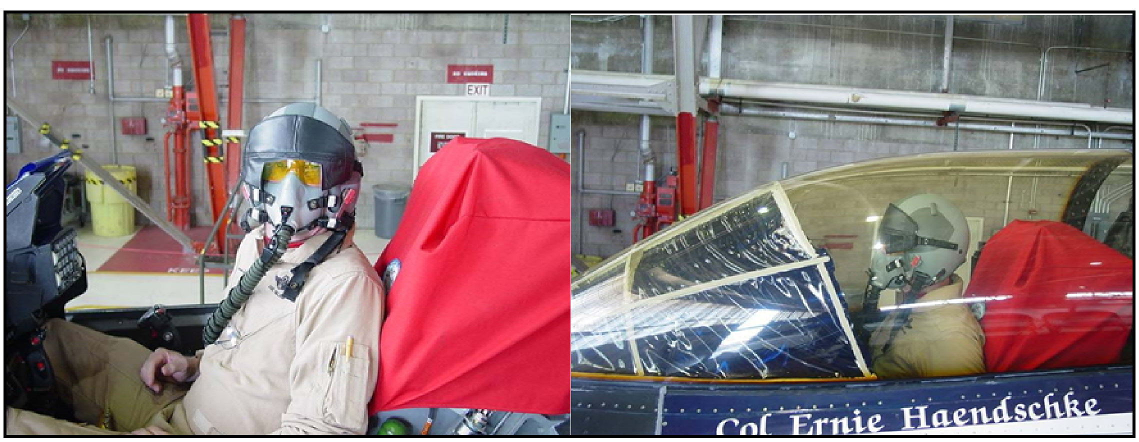


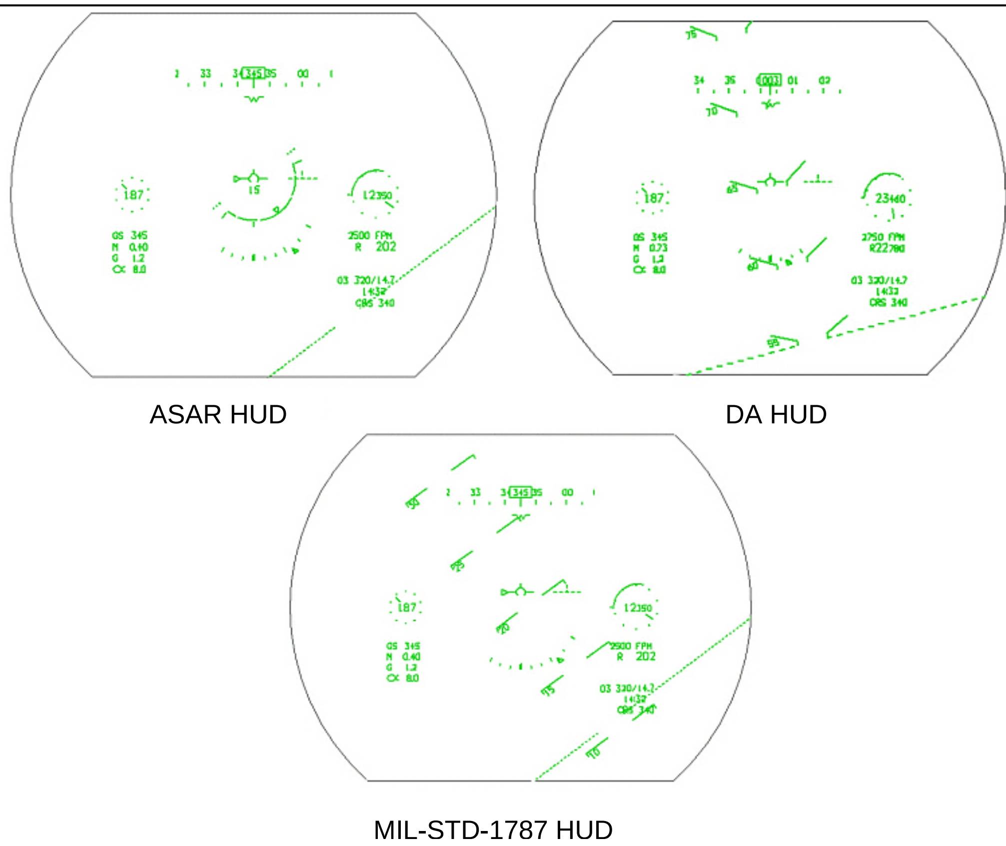
Figure 13 Pilot in the VISTA NF-16D Wearing Vision Restriction Device with Blue Vinyl Masking on Canopy

UNUSUAL ATTITUDE RECOVERY

Test Methodology:

Speed and Correctness of Control Inputs.

The VISTA ground flight-simulation mode was used to familiarize pilots with the HUD symbology and to collect baseline data for the simulated UARs prior to actual flight test. Once pilots were able to complete practice UARs with 100% correct recovery responses, they were allowed to proceed on to flight trials. The ground-based simulation in VISTA was deemed necessary due to the varied flight training background among the evaluation pilots that could impact how they performed the UAR. For flight trials, UARs using the ASAR, DA, and the MIL-STD-1787C HUD symbology sets were compared. A representation of the three symbol sets during unusual attitude conditions is shown in figure 14. First significant control inputs and time to first significant control inputs were measured. First significant control inputs were defined as any one or combination of: 1) pitch force: 5 pounds, 2) roll force: 3 pounds, or 3) throttle input: 0.4 inches. The time to first significant control input was defined as the time from presentation of symbology to initiation of control input. The AFM 11-217 (reference 6) UAR procedures used to determine correctness of initial stick input for climb and dive conditions are shown in table 1.



Notes:
1. ASAR - arc segment attitude reference
2. HUD - head-up display
3. DA - dual articulated

Figure 14 Unusual Attitude Recovery Symbology for ASAR, DA, and MIL-STD-1787C HUD

Table 1 Air Force Manual 11-217 Unusual Attitude Recovery Correct Input Procedures by Condition

Scenario No.	Unusual Attitude	Roll Force	Pitch Force	Throttle Input
1	> 20° Nose High > 300 KIAS	Roll in the direction that is the shortest distance to 90° AOB	Aft input after AOB ≈ 90°	Aft Movement
2	> 20° Nose High < 300 KIAS	Roll in the direction that is the shortest distance to 90° AOB	Aft input after AOB ≈ 90°	Forward Movement
3	Nose Low > 300 KIAS	Roll in the direction that is the shortest distance to wings level, upright flight	Aft input after AOB < 90°	Aft Movement
4	Nose Low < 300 KIAS	Roll in the direction that is the shortest distance to wings level, upright flight	Aft input after AOB < 90°	Forward Movement

Notes:
1. The aircraft will not be unloaded toward 0 g to increase roll performance.
2. AOB - angle of bank
3. No. - number

Prior to data collection, pilots became familiar with each of the three formats by performing a series of simulated roll, loop, and barrel-roll maneuvers.

The UAR task was conducted as follows:

1. The initial conditions prior to beginning each UAR task were 350 KIAS at 15,000 feet MSL.

2. All pilots began the ground and flight test points with their eyes and head positioned forward to view the HUD, i.e., within the HUD design eye "box," eyes shut, and amber visor down.

3. The pilot called, "Ready," and the SP started the VSS masking maneuver sequence. The VISTA was automatically maneuvered to the desired UAR test conditions using a preprogrammed masking maneuver that attempted to hide the test UAR condition through false vestibular cueing.

4. After the masking maneuver was complete, the VSS sounded a 2-second tone, simultaneously displayed the appropriate symbology depicting the unusual attitude initial conditions, and started recording time and control inputs.

5. At the tone, the pilot opened his eyes, viewed the symbology presented, and used it to recover from the unusual attitude displayed in accordance with (IAW) the procedures in table 1.

6. The UAR task was halted. Total time to recovery was taken after the pilot had recovered the aircraft so the climb-dive marker was within ±2 degrees of the horizon for 2 seconds and wings level, i.e., ≤10 degrees of bank. At this point, another 2-second tone sounded signaling the task was over.

Initial reaction time from tone until first significant control input was measured for all three symbology formats. The correctness of first significant roll, pitch, and throttle control input using the ASAR HUD was compared to that when using the DA and the MIL-STD-1787C HUD.

The UAR initial conditions presented to each pilot are displayed in table 2. The order of presentation was randomized across UAR conditions.

Table 2 Ground and Flight Unusual Attitude Recovery (UAR) Initial Conditions

UAR No.	Pitch Attitude (deg)	Roll Attitude (deg)	Airspeed (KIAS)
1	+60	0	400
2	+60	+120	270
3	-30	-45	400
4	-30	+150	250
5	-60	+60	400
6	-60	-135	400
7	+30	+90	170
8	+30	-135	300

Note: No. - number

Workload and Situation Awareness (SA).

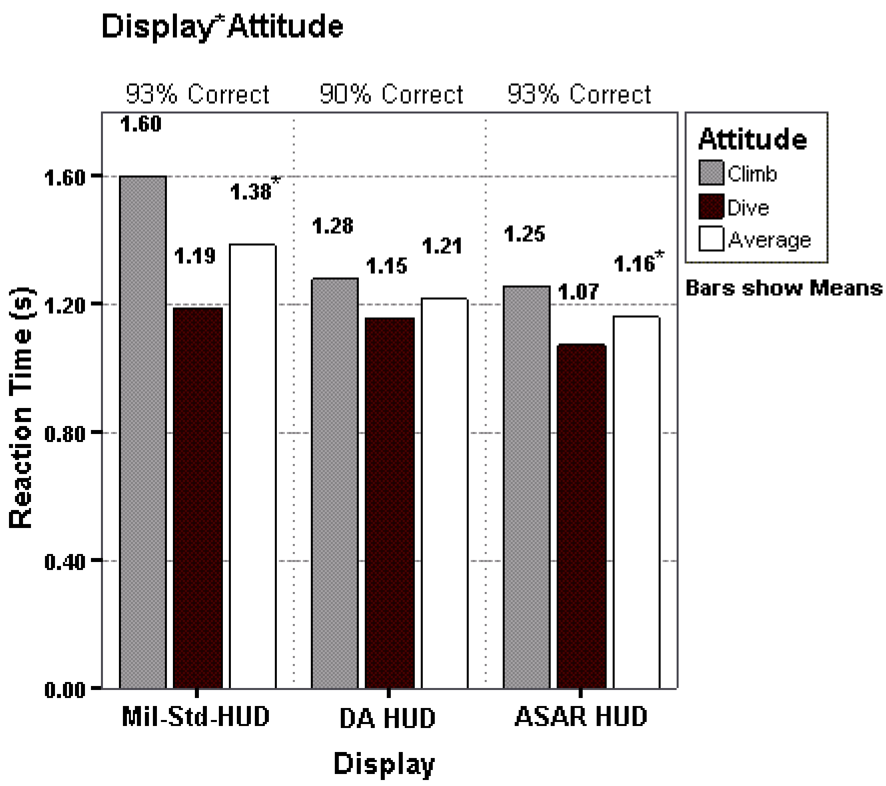
Each pilot rated the ASAR, DA, and MIL-STD-1787C HUD formats using the MCH and CLSA rating scales (appendix B) immediately following completion of the UAR. The VISTA HUD tapes were analyzed to help determine the correctness of UARs for both ground and flight tests. In addition, verbal comments were recorded postflight and HUD acceptability questionnaires completed.

Test Results:

An analysis-of-variance (ANOVA) was performed to determine if there were statistically significant differences between UAR initial stick input reaction times for the three HUD formats. The results from the ANOVA are presented in appendix C. Reaction time using the ASAR HUD was statistically significantly faster than when using the MIL-STD-1787C HUD. However, reaction time using the ASAR HUD was not statistically significantly faster than when using the DA HUD. The difference between reaction times for dive UARs (Mean = 1.15 secs) and climb UARs (Mean = 1.38 secs) using the ASAR HUD was statistically significant when compared to using the MIL-STD-1787C HUD. The difference in reaction time for the DA HUD and MIL-STD-1787C HUD was not statistically significant. A second ANOVA was performed to determine if there were statistically significant differences between the correctness of control inputs for the three HUD formats. No statistically significant differences were found (figure 15).

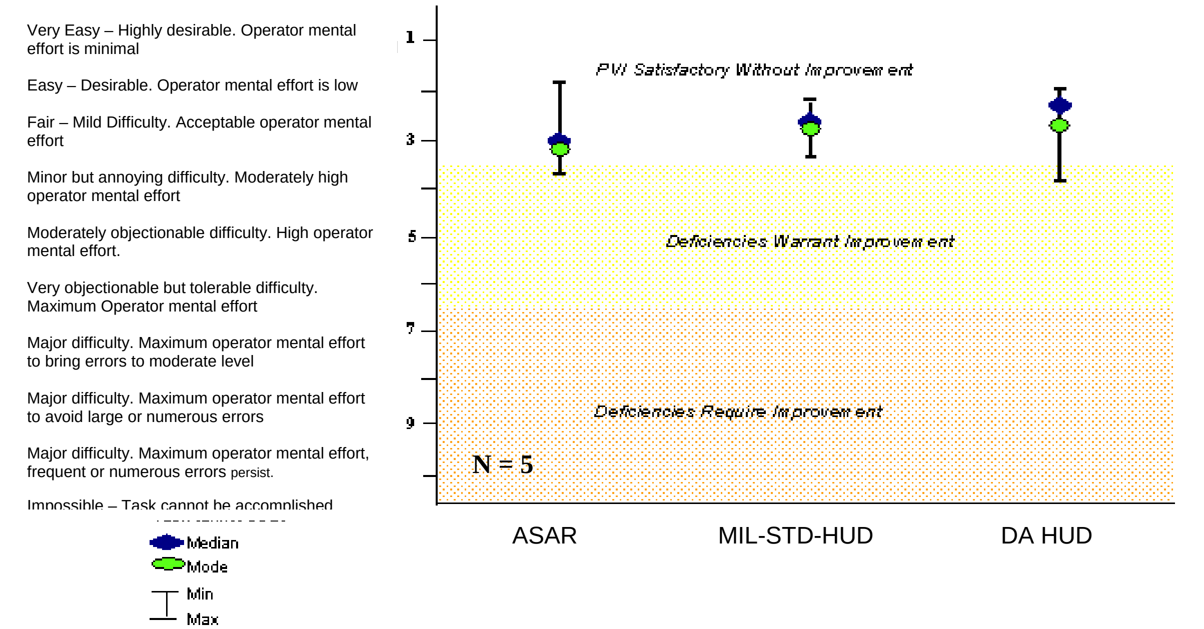
HUD Acceptability, Workload, and SA.

All three of the HUD formats were satisfactory for performing unusual attitude recoveries. Median HUD acceptability ratings were satisfactory for all three HUD formats. Pilot workload and situation awareness during UARs were also satisfactory (figures 16 and 17).



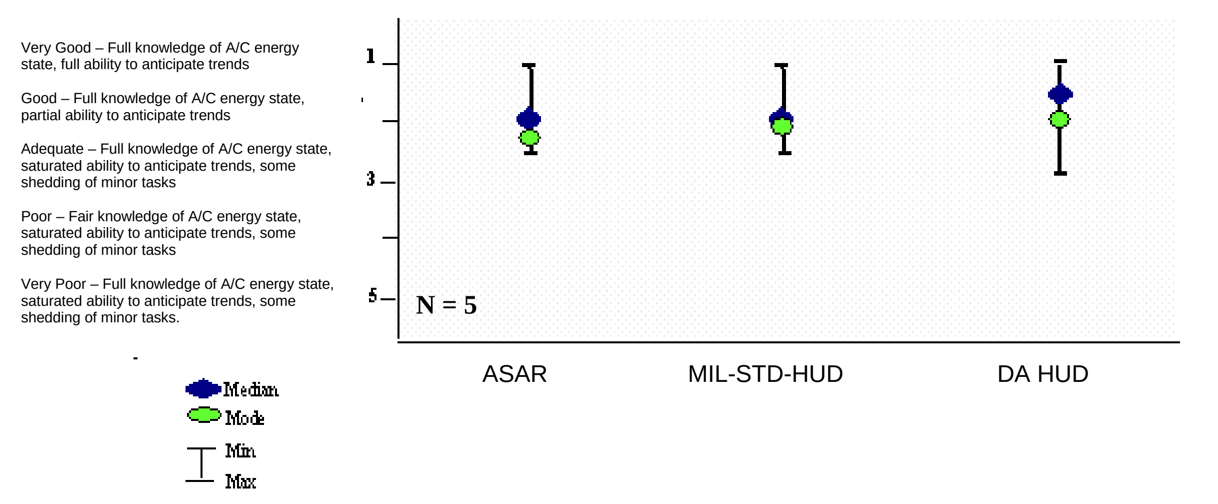
Notes:
1. Asterisk (*) denotes a statistically significant effect.
2. RT - reaction time
3. HUD - head-up display
4. DA - dual articulated
5. ASAR - arc segment attitude reference

Figure 15 Reaction Time and Percent Correct for Unusual Attitude Recoveries Using the MIL-STD, DA, and ASAR HUD Symbology Sets



Notes: 1. ASAR - arc segment attitude reference
2. HUD - head-up display
3. DA - dual articulated

Figure 16 Unusual Attitude Recovery Modified Cooper-Harper Workload Ratings Using the ASAR, MIL-STD, and DA HUD Symbology Sets



Notes: 1. A/C - aircraft
2. ASAR - arc segment attitude reference
3. HUD - head-up display
4. DA - dual articulated

Figure 17 Unusual Attitude Recovery China Lake Situation Awareness Ratings Using the ASAR, MIL-STD, and DA HUD Symbology Sets

The ASAR symbology provided immediate situation awareness of aircraft attitude as well as the magnitude of the deviation from the horizon line. The ASAR horizon/ground pointer and digital readout were very useful for performing UARs, and the ASAR circle circumference segmentation provided a clear indicator of the approaching horizon. The direction to the horizon was clear, which allowed pilots to easily determine the correct roll/pitch input despite the fact that the horizon line was frequently out of their field of view. Minimal familiarization training was required to obtain a sense of pitch rate correlation to the rate that the ASAR circle circumference decreased or increased. One pilot characterized completing UARs with the ASAR HUD as intuitive and easily accomplished. The ASAR HUD was also excellent for very nose-low UARs, providing the quickest visual feedback on which direction to roll and pull to recover. One pilot reported the ASAR was much better than the MIL-STD-1787C HUD for UARs; however, another pilot noted that the ASAR was not as good an aid in nose-high UARs. A third pilot reported that nose-high recovery was as good as when using the DA HUD format.

VERTICAL S-B DYNAMIC MANEUVERING

Test Methodology:

HUD Acceptability, Workload, and SA.

Head-up display acceptability, workload and situation awareness were measured while maintaining airspeed, altitude, bank, and vertical velocity within preset bounds during vertical S-B dynamic maneuvering (reference 6).

The vertical S maneuvers were proficiency maneuvers designed to improve a pilot's crosscheck and aircraft control. The vertical S-B maneuver was a continuous series of rate climbs and descents flown on a constant heading (figure 18). A constant AOB of 30 degrees was maintained during the climb, turn, and descent.

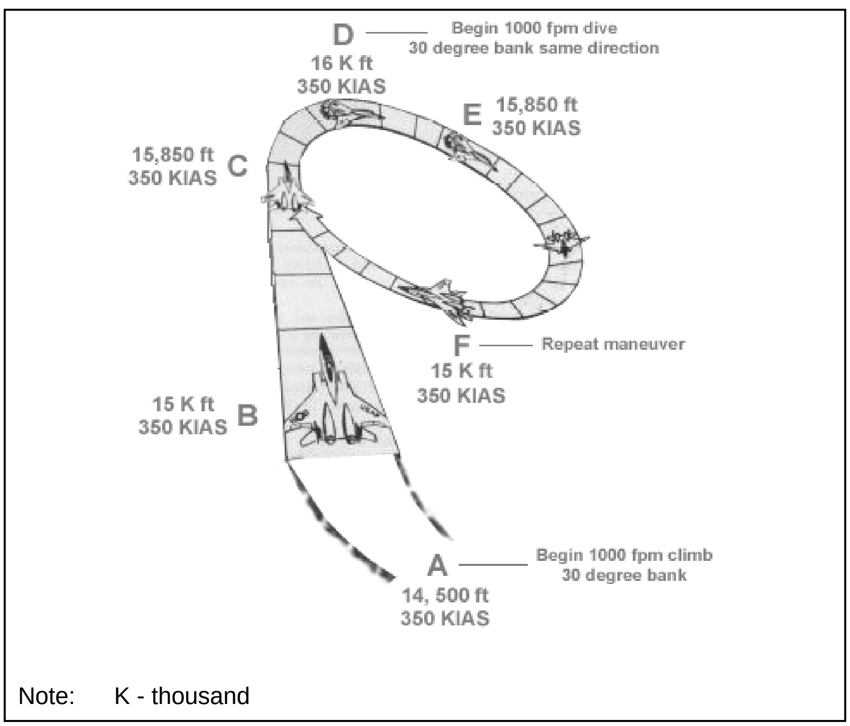


Figure 18 Vertical Banked S-Turn Dynamic Maneuvering Task

Ground testing, using the VSS, and flight tests were conducted using the same vertical S-B procedures. During both phases of testing, a VRD was used to eliminate external distractions and to simulate IMC conditions. All altitudes were MSL. The vertical S-B task procedure was:

1. The aircraft was flown to 14,500 feet at an airspeed of 350 KIAS, and the SP armed the instrumentation system timing of the VISTA. This was done to establish the aircraft on bank and vertical velocity prior to the data collection start point at 15,000 feet.

2. At 14,500 feet, the SP called, "Action," and the test maneuver was initiated. The pilot flew the aircraft in a climb from 14,500 to 16,000 feet at 1,000 fpm maintaining a 30-degree AOB and 350 KIAS.

3. At 16,000 feet, the pilot began a descent to 15,000 feet at 1,000 fpm, maintaining a 30-degree AOB and 350 KIAS.

4. The task was complete when the pilot recovered the aircraft to 15,000 feet, 350 KIAS, and initiated another vertical S-B maneuver to 200 feet above 15,000 feet. This was done to determine the precision with which the pilot reached the task end point.

The VISTA instrumentation system monitored and displayed bank angle, airspeed, altitude, and vertical velocity maintenance in terms of desired, adequate, or unsatisfactory performance (table 3). This information was displayed in the lower left quadrant of the HUD. The SP performed aircraft system crosscheck, visual clearing, and monitored ground clearance altitudes and dive angles. The F-16 control laws were used in the VISTA for all vertical S-B flight tests.

Verbal comments of the pilot were recorded during and after each test point. The pilots also provided an MCH and CLSA rating immediately following the vertical S-B maneuver along with a HUD acceptability rating.

Pilot Performance Rating.

The VSS determined the level of performance based on the criteria in table 3.

Table 3 Vertical Banked S-Dive (S-B) Evaluation Criteria

Maneuver	Event	Rating	
		Desired (95% of the time during task)	Adequate (90% of the time during task)
Vertical S-B	Climb: 1,000 feet 1,000 fpm 30° bank; *then* Descend: 1,000 feet 1,000 fpm 30° bank same direction - Recover to original altitude and airspeed	Airspeed ± 10 KIAS Bank ± 5° Vertical Velocity ± 200 fpm (once established) Altitude ± 100 feet	Airspeed ± 15 KIAS Bank ± 8° Vertical Velocity ± 250 fpm (once established) Altitude ± 150 feet

When the aircraft reached 15,850 feet during the climb portion of the maneuver (phase C of figure 18), vertical velocity measurement was stopped until 15,850 feet on the descent portion of the maneuver (phase E of figure 18). The first altitude measurement was taken at the apex of the maneuver (phase D of figure 18). Task performance measurement for airspeed, bank, and vertical velocity ended when the aircraft reached an altitude of 15,150 feet on the descent portion of the vertical S-B maneuver. The second altitude measurement was taken at the bottom-out portion of the maneuver (phase F of figure 18). To accurately determine the lowest point of the maneuver, the pilot initiated another vertical S-B maneuver until reaching 15,200 feet. At this point the test was terminated.

Test Results:

HUD Acceptability, Workload and SA.

All three HUD formats, including the ASAR HUD, were satisfactory for performing the vertical S-B maneuvers. Median HUD acceptability ratings were satisfactory for all three HUD formats. Pilot workload and situation awareness were also satisfactory for all three formats (figures 19 and 20). However, precise vertical velocity control within desired parameters was difficult to maintain due to the limited ability to discern small deviations in pitch attitude from the ASAR format. This resulted in continuous oscillations in vertical velocity and undesirable flight path angle (FPA) deviations any time the pilot's airspeed scan exceeded one second. One solution may be an analog FPA indication ("odometer-type") that would provide a more precise indication of FPA, and also quickly and clearly indicate rate trends. **The ASAR HUD symbology should be improved to provide more attitude awareness and precise aircraft control when within ±10 degrees of the horizon. (R1)**[1]

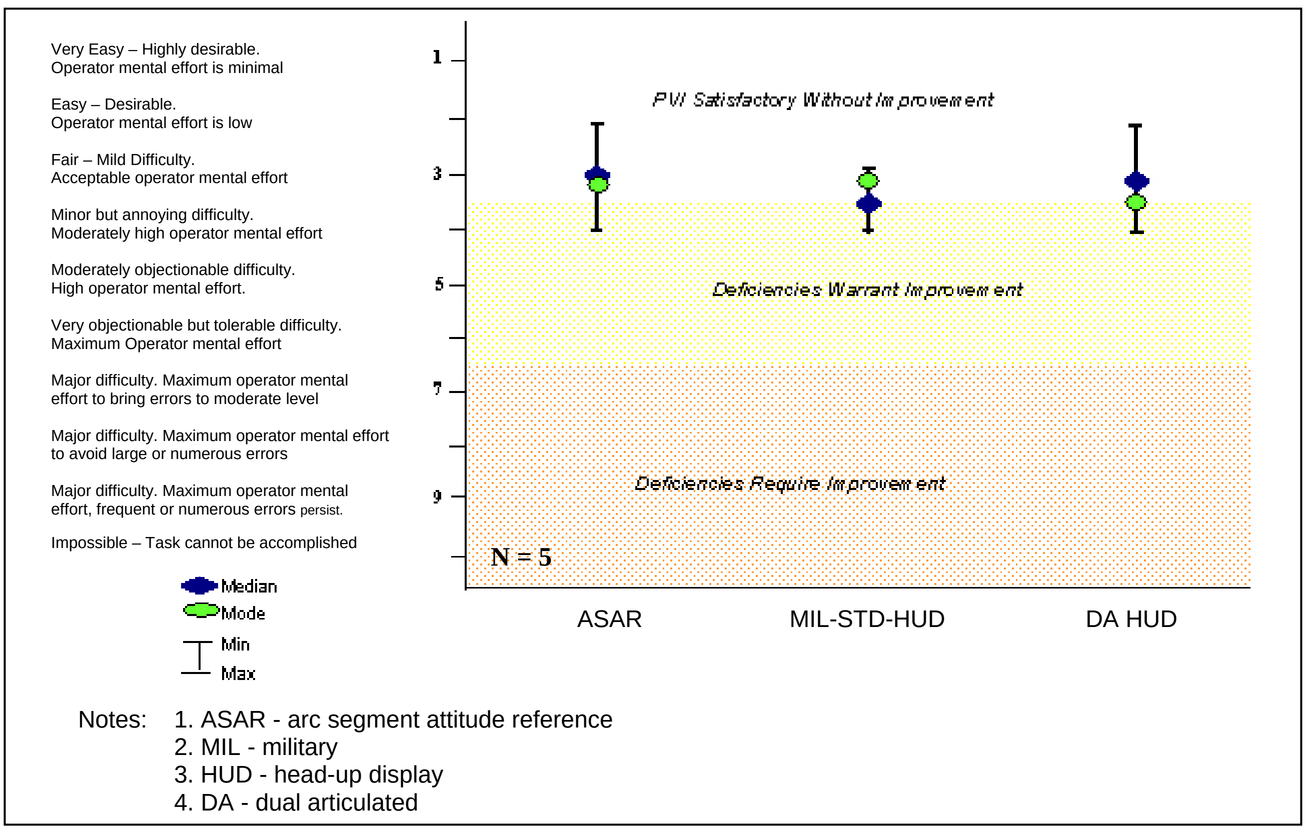
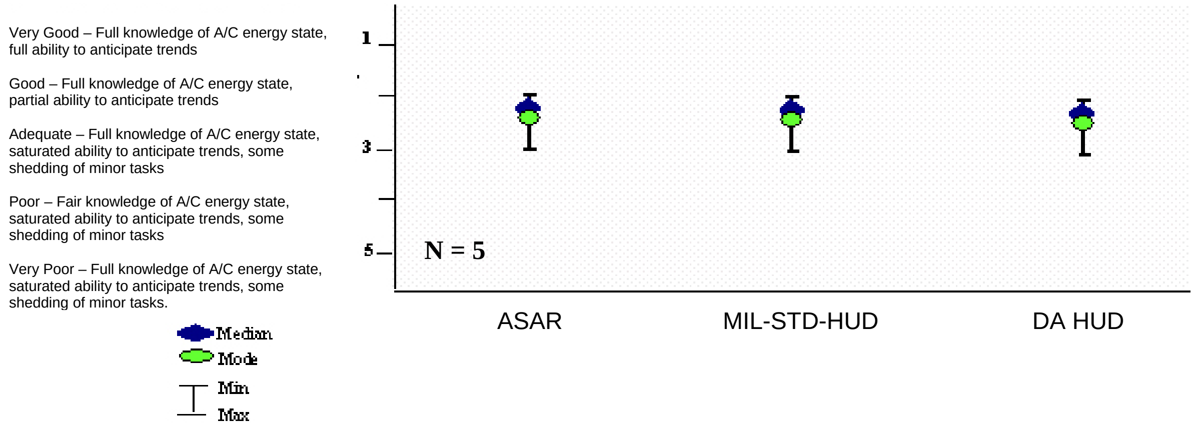


Figure 19 Vertical Banked S-Turn Modified Cooper-Harper Workload Ratings by Symbology

[1] Numerals following an R represent recommendation numbers tabulated in the Conclusions and Recommendations section.



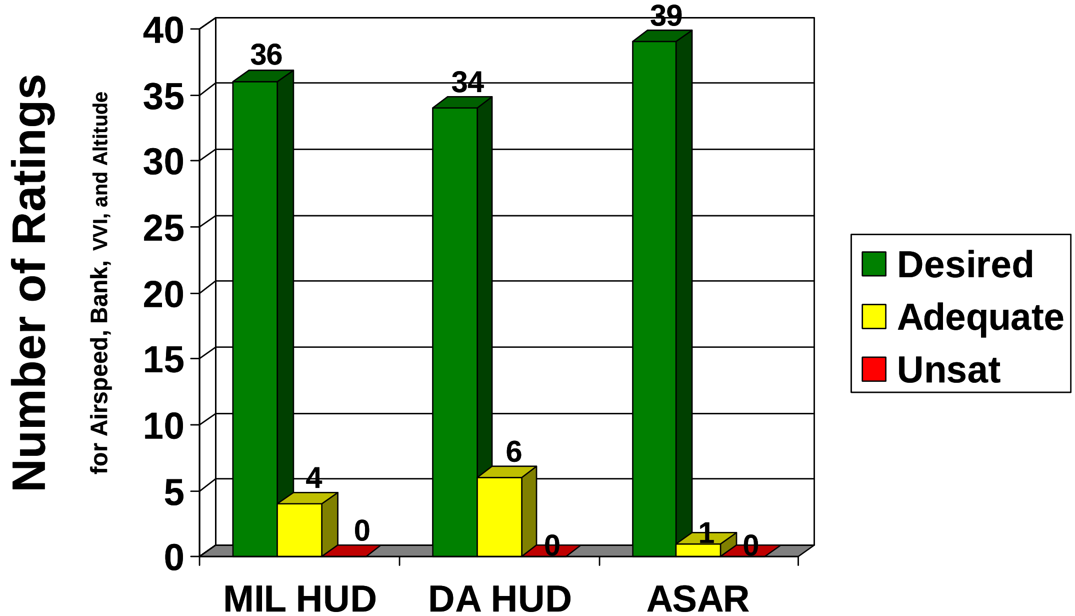
Notes: 1. ASAR - arc segment attitude reference
2. MIL - military
3. HUD - head-up display
4. DA - dual articulated

Figure 20 Vertical Banked S-Turn China Lake Situation Awareness Ratings by Symbology

The VISTA NF-16D handling qualities made it difficult to make fine vertical velocity changes. This was an issue because vertical velocity, airspeed, and AOB information were the primary factors for successfully completing the S-B patterns. There was no difference in performance of these tasks using either the ASAR attitude display or the VISTA vertical velocity, airspeed, and AOB display. However, the VISTA tape vertical velocity display was difficult to use because it jumped a couple of hundred feet per minute. This forced the pilot to use VISTA digital vertical velocity information as the primary reference, which required more concentration to detect trends.

Pilot Performance Rating.

The number of pilot performance ratings for the vertical S-B maneuvers for the ASAR HUD was comparable to those of the DA and MIL-STD-1787C HUD formats (figure 21). The ASAR HUD symbology achieved the most desired ratings with the fewest adequate ratings; however, none of the HUD formats received unsatisfactory performance ratings. For this task, the MIL-STD-1787C and DA HUD formats were essentially the same since the vertical S-B task was performed near the horizon and ladder articulation (bending) was minimal. Changing the digital readout of climb-dive angle to an analog display may improve the capability of the ASAR to provide more precision in attitude awareness when within ±10-degrees of the horizon. An example of how this could be implemented on the ASAR display is shown in figure 22. This may also balance any disadvantage presented from the symbology compression (i.e., ASAR not one-to-one analog of real world climb-dive angles). **The ASAR HUD symbology should be improved to provide more attitude awareness and precise aircraft control when within ±10 degrees of the horizon. (R1)**



Pilots: 5

Trials: 10 (2 each for Vertical S-B)

Max Correct Score: 40 (4 parameters x 2 trials x 5 pilots)

Notes:
1. VVI - vertical velocity indication
2. MIL - military
3. HUD - head-up display
4. DA - dual articulated
5. ASAR - arc segment attitude reference

Figure 21 Vertical Banked S-Turn (S-B) Piloting Task Results by Head-Up Display Format

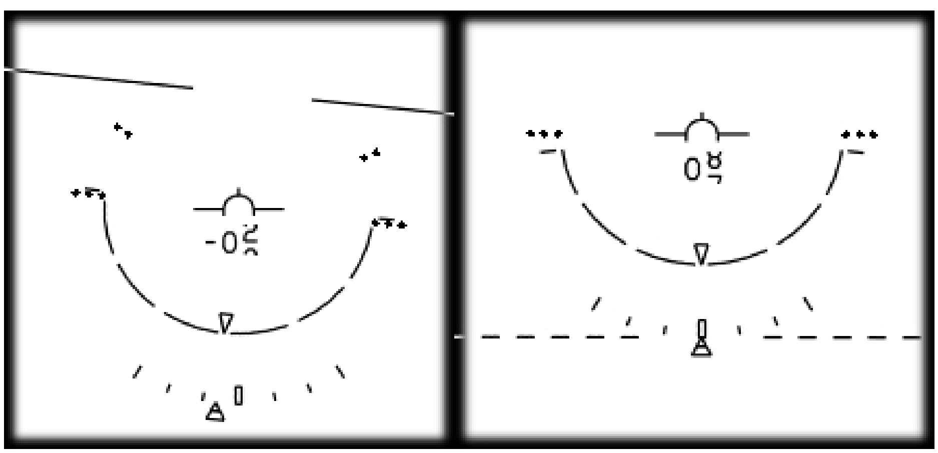


Figure 22 Arc Segment Attitude Reference Head-Up Display with an Analog Odometer-Type Flightpath Angle Readout (-2.5-Degree Dive and +7.5-Degree Climb)

VERTICAL S-D DYNAMIC MANEUVERING

Test Methodology:

HUD Acceptability, Workload, and SA.

Head-up display acceptability, workload, and situation awareness were measured while maintaining airspeed, altitude, bank, and vertical velocity within preset bounds during vertical S-D dynamic maneuvering (reference 6).

The vertical S maneuvers were proficiency maneuvers designed to improve a pilot's crosscheck and aircraft control. The vertical S-D maneuver was the same as the vertical S-B, except that the initial AOB was 45 degrees and the direction of turn was reversed simultaneously with each change of vertical direction (figure 23).

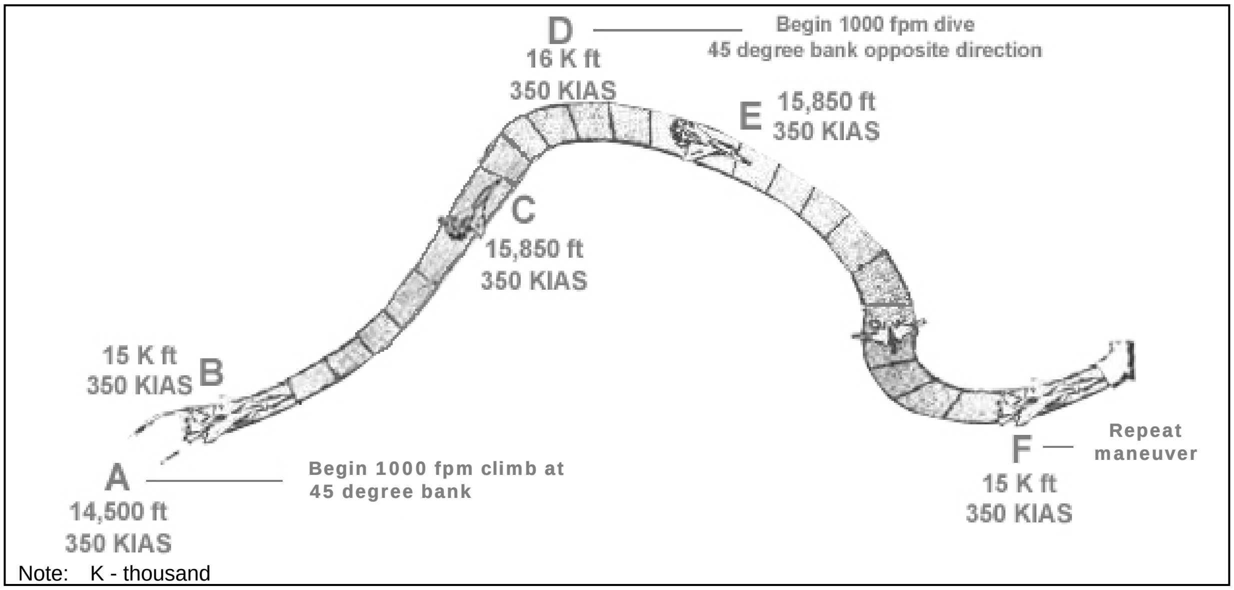


Figure 23 Vertical Dive S-Turn Dynamic Maneuvering Task

Ground testing, using the VSS, and flight tests were conducted using the same vertical S-D procedures. During both phases of testing, a VRD was used to eliminate external distractions and to simulate IMC conditions. All altitudes were MSL. The vertical S-D task procedure was:

1. The aircraft was flown to 14,500 feet at an airspeed of 350 KIAS and the SP armed the instrumentation system timing of the VISTA. This was done to establish the aircraft on bank and vertical velocity prior to the data collection start point at 15,000 feet.

2. At 14,500 feet, the SP called, "Action," and the test maneuver was initiated. The pilot flew the aircraft to 16,000 feet at 1,000 fpm, while maintaining a 45-degree AOB and 350 KIAS.

3. At 16,000 feet, the pilot began a descent to 15,000 feet at 1,000 fpm, while maintaining a 45-degree AOB *in the opposite direction*, at an airspeed of 350 KIAS.

4. The task was complete when the pilot recovered the aircraft to 15,000 feet, 350 KIAS, and initiated another vertical S-D maneuver to 200 feet above 15,000 feet. This was done to

determine the precision with which the pilot reached the task end point of the maneuver (i.e., 15,000 feet).

The VISTA instrumentation system monitored and displayed bank angle, airspeed, altitude, and vertical velocity maintenance in terms of desired, adequate, or unsatisfactory performance. This information was displayed in the lower left quadrant of the HUD. The SP performed aircraft system crosscheck, visual clearing, and monitored ground clearance altitudes and dive angles. The F-16 control laws were used in the VISTA for all vertical S-D flight tests.

Verbal comments of the pilot were recorded during and after each test point. The pilot also provided an MCH and CLSA rating immediately following the vertical S-D maneuver along with a HUD acceptability rating.

Pilot Performance Rating.

The desired and adequate performance ratings were counted for airspeed, altitude, bank, and vertical velocity from the target performance criteria specified in table 4 during vertical S-D maneuvering. Performance ratings were collected for all three formats.

When the aircraft reached 15,850 feet during the climb portion of the maneuver (phase C of figure 23), vertical velocity and bank measurement was stopped until 15,850 feet on the descent portion of the maneuver (phase E of figure 23). The first altitude measurement was taken at the apex of the maneuver (phase D of figure 23). Task performance measurement for airspeed, bank, and vertical velocity ended when the aircraft reached 15,150 feet on the descent portion of the maneuver. The second altitude measurement was taken at the bottom-out portion of the maneuver (phase F of figure 23). To accurately determine the lowest point of the maneuver, the pilot initiated another vertical S-D maneuver until reaching 15,200 feet. At this point the test was terminated.

Table 4 Vertical Dive S-Turn (S-D) Evaluation Criteria

Maneuver	Event	Rating: Desired (95% of the time during task)	Rating: Adequate (90% of the time during task)
Vertical S-D	Climb: 1,000 feet 1,000 fpm 45° bank; *then* Descend: 1,000 feet 1,000 fpm 45° bank in the opposite direction - Recover to original altitude and airspeed	Airspeed ±10 KIAS Bank ±5° Vertical Velocity ± 200 fpm (once established) Altitude ±100 feet	Airspeed ±15 KIAS Bank ±8° Vertical Velocity ± 250 fpm (once established) Altitude ±150 feet

Test Results:

HUD Acceptability, Workload, and SA.

All three HUD formats were satisfactory for performing the vertical S-D maneuvers. Median HUD acceptability ratings were equal for all three HUD formats. Pilot workload was satisfactory for the DA HUD and marginal for the ASAR and MIL STD-1787C HUDs (figure 24). Situation awareness was satisfactory for all three formats (figure 25).

During the first reversal on the first S-D maneuver using the ASAR HUD, the pilot inadvertently rolled to 60 degrees instead of 45 degrees and maintained 60 degrees for approximately 1 to 2 seconds before realizing the error. This was due to the bank scale tick marks for 30, 45, and 60 degrees being too similar in size to each other. The pilot suggested that the 45-degree tick mark could be modified, either made smaller or larger, to be more distinct. Precise vertical velocity control was also a significant concern. The slow scan required during subsequent corrections for vertical velocity, bank angle, and airspeed resulted in the pilot being "behind" the airplane throughout the descent. With the pilot's attention focused on correcting the error, the aircraft rate of descent increased. This resulted in an adequate performance rating. The second S-D maneuver the pilot completed showed improved performance, but with more attention diverted to maintaining the correct bank angle, and a much slower roll reversal transition. Similar comments concerning vertical velocity control were made during the S-B maneuvers.

The VISTA F-16 handling qualities and vertical situation indicator (VSI) displays were again the main factors influencing performance of the S-D maneuvers. The VISTA handling qualities made it very difficult to make fine VSI changes. It made no difference in performance which attitude display was used because the VSI, airspeed, and AOB displays were the principal displays required to accomplish the maneuver. However, the tape VSI display was difficult to use because it jumped a couple of hundred feet per minute. This forced the pilot to use the digital VSI as the primary reference, which took more concentration to detect trends. Although an attitude display was not the key to performing this maneuver, the lack of a pitch ladder was again noted as a minor annoyance.

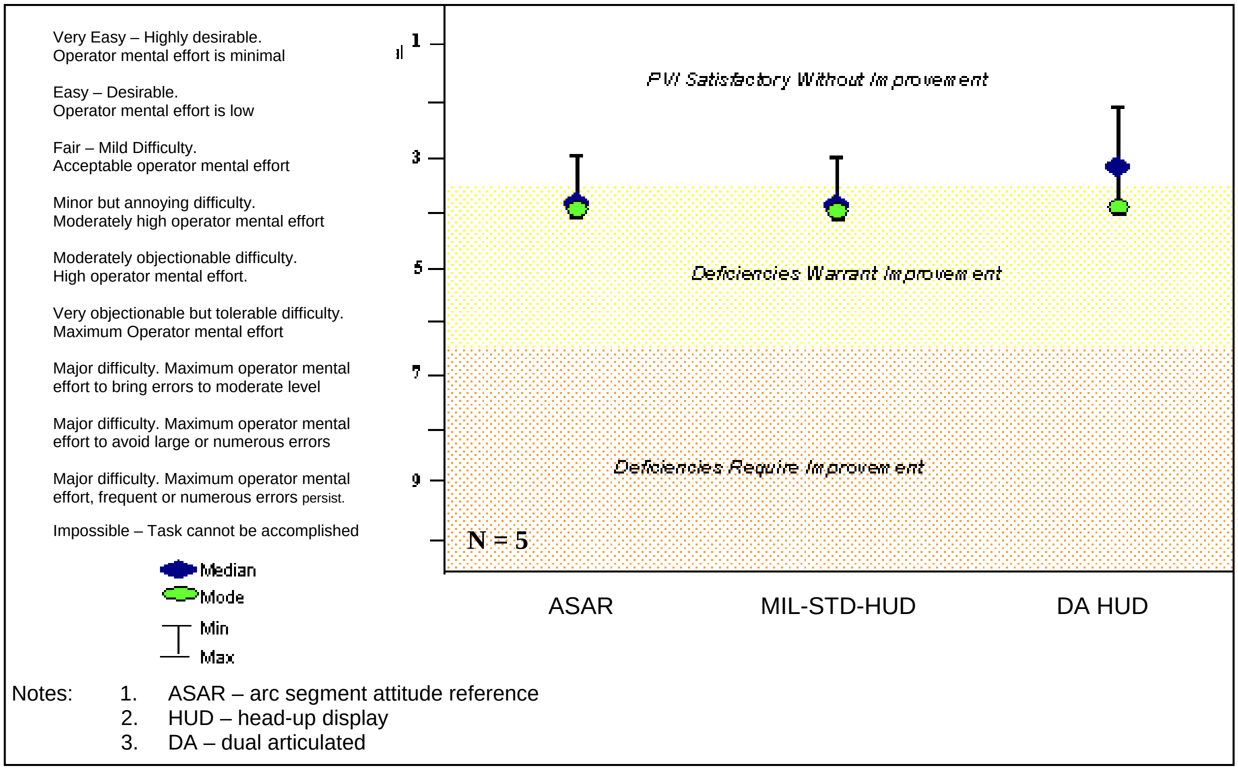


Figure 24 Vertical Dive S-Turn Modified Cooper-Harper Results by Head-Up Display Format

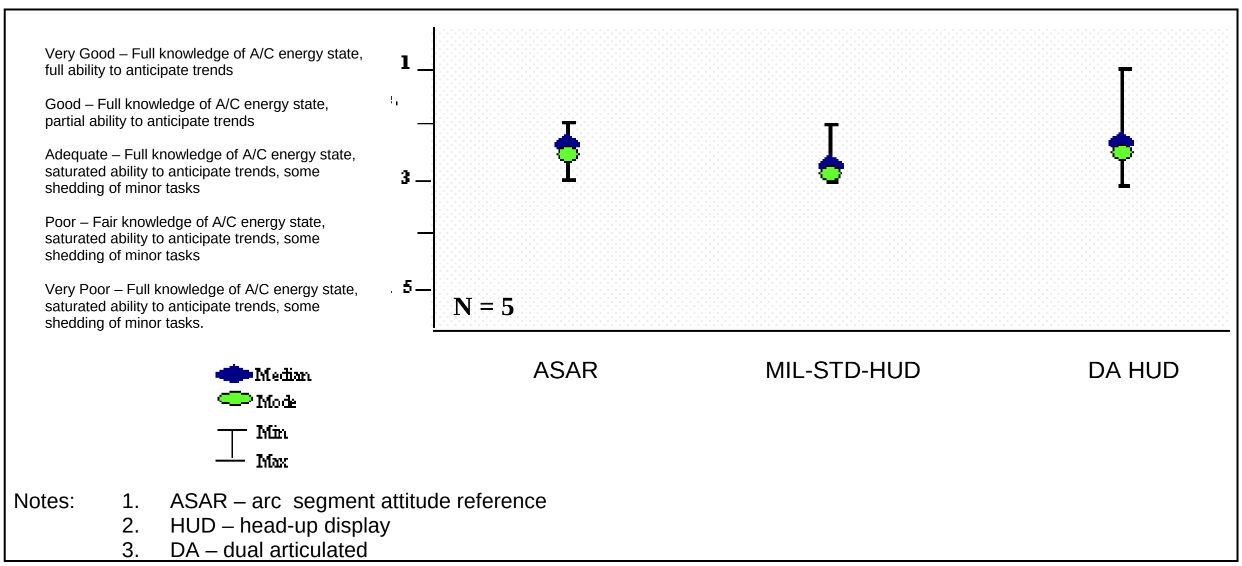
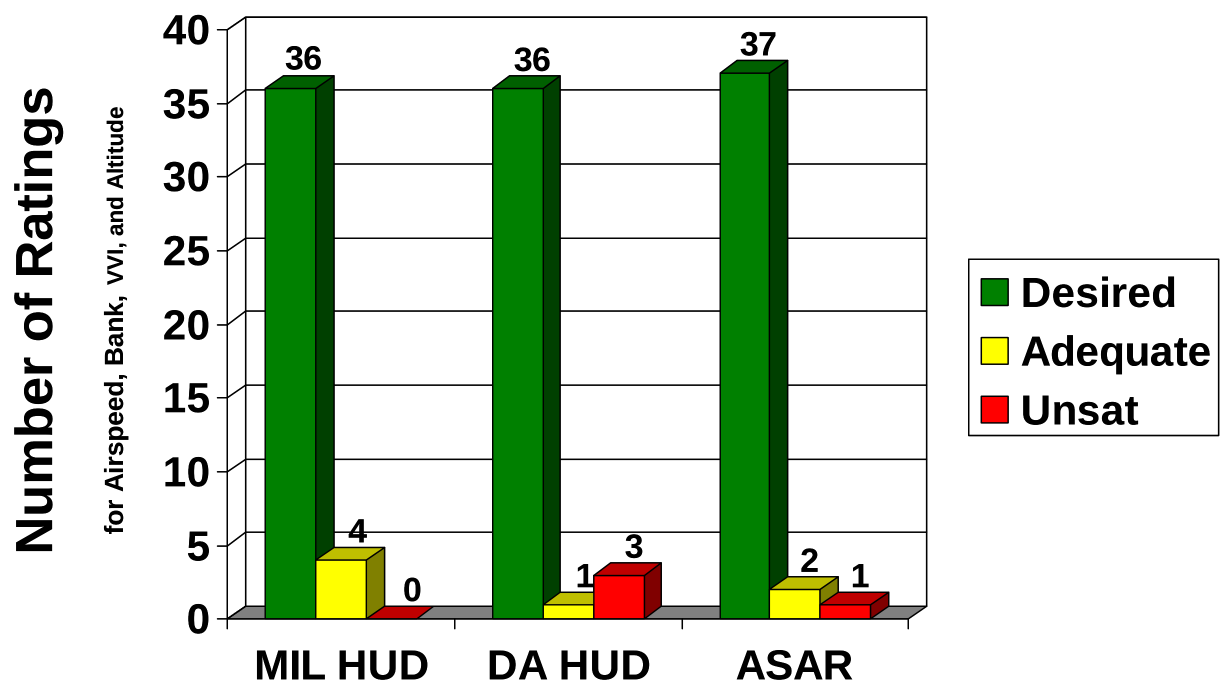


Figure 25 Vertical Dive S-Turn China Lake Situation Awareness Results by Head-Up Display Format

<u>Pilot Performance Rating.</u>

The pilot performance ratings for all three HUD formats were in the desired range (figure 26). For the vertical S-D maneuvers, the MIL-STD-1787C HUD and DA HUD symbology were essentially the same, since the tasks were performed near the horizon and ladder articulation was minimal. Changing the climb-dive angle digital display to an analog odometer type display may improve the precision required for attitude control near the horizon, especially during vertical S-D maneuvers. Using this type of format when within ±10-degrees of the horizon may balance any disadvantage presented from the symbology compression, that is, the ASAR not presenting a one-to-one analog of real world climb-dive angles. **The ASAR HUD symbology should be improved to provide more attitude awareness and precise aircraft control when within ±10 degrees of the horizon. (R1)**



Pilots: 5

Trials: 10 (2 each for Vertical S-D)

Max Correct Score: 40 (4 parameters x 2 trials x 5 pilots)

Notes:
1. VVI - vertical velocity indication
2. MIL - military
3. HUD - head-up display
4. DA - dual articulated
5. ASAR - arc segment attitude reference

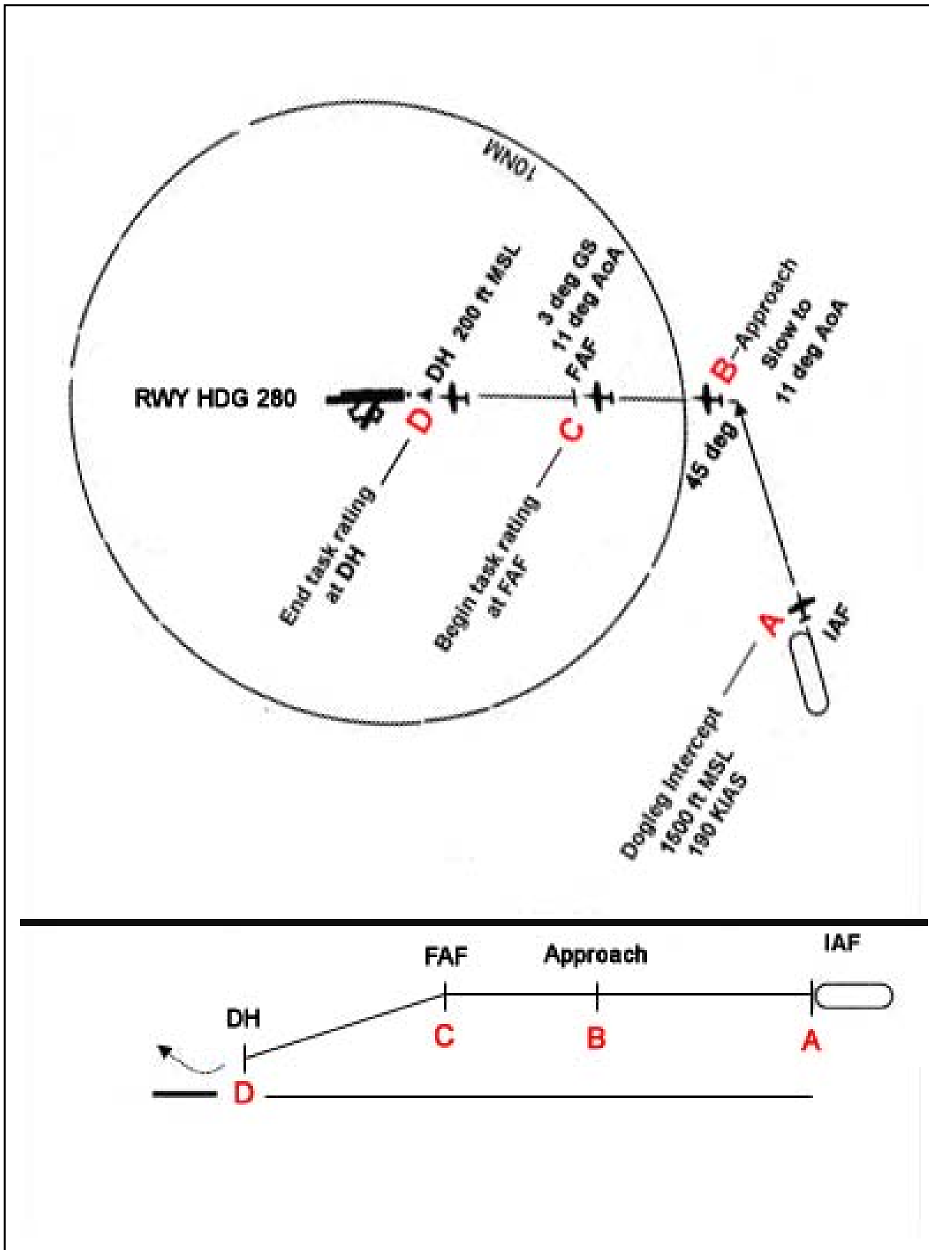
Figure 26 Vertical Dive S-Turn Task Results by Head-Up Display Format

ILS PRECISION APPROACH

Test Methodology:

Ground and flight tests were conducted using the same ILS approach procedures for all three HUD formats. Ground testing was accomplished using the VSS system. A VRD was used to reduce external distractions during ground testing and simulate IMC conditions during flight. Figure 27 shows an illustration of the ILS approach maneuver.

The SP initiated the simulated ILS task, configured the appropriate HUD symbology, and initialized the flight director. The SP then armed the instrumentation system timing of the VISTA prior to the action point. Once conditions were met, the SP called, "Action," and the test run started. The simulated ILS approaches were conducted using the on-board computing capabilities of the VISTA. A 'runway-in-the-sky' was created to simulate an ILS approach to a go-around at the 200 feet MSL decision height point.



Notes:
1. DH - decision height
2. GS - groundspeed
3. AOA - angle of attack
4. FAF - final approach fix
5. IAF - initial approach fix

Figure 27 ILS Precision Approach Task

An ILS was simulated using the inertial navigation system data. The VISTA NF-16D gear and flaps were lowered to simulate an actual landing. The task consisted of four phases: dogleg intercept; approach; ILS tracking; and go-around point. The ILS was flown with only raw data (no flight director was displayed) to increase the pilot's reliance on the HUD attitude reference for completion of the task. The ILS testing procedure was:

1. Upon SP activation, the aircraft was initialized at the starting point of the task. The pilot flew a 45-degree dogleg toward the final approach course (phase A of figure 27). Initial airspeed was approximately 190 KIAS with an altitude of 13,500 feet MSL (displayed as 1,500 feet MSL).

2. Upon intercepting the approach course (phase B of figure 27), a 2.5-degree glide slope approach with an 11-degree angle of attack (AOA) was executed to a simulated runway. Altitude was maintained at 1,500 feet until intercept of the glideslope (phase C of figure 27).

3. The glide slope and localizer were tracked to decision height (200 feet), at which time the 'virtual runway' appeared (phase D of figure 27). The pilot signaled the decision height point, and the test was complete.

The VISTA instrumentation system monitored and displayed course, glide slope, and AOA maintenance in terms of desired or adequate performance. The SP performed aircraft system crosscheck, visual clearing, and monitored ground clearance altitudes and dive angles. The F-16 control laws were used in the VISTA for all ILS approach flight tests. Following each ILS approach task, performance criteria achieved for ILS course, glideslope, and AOA was displayed in the lower left quadrant of the VISTA HUD. An example of the ASAR HUD symbology configured for ILS precision approach is shown in figure 28. After the task, the pilot provided an MCH and CLSA rating. A HUD acceptability questionnaire was also completed and pilot comments recorded.

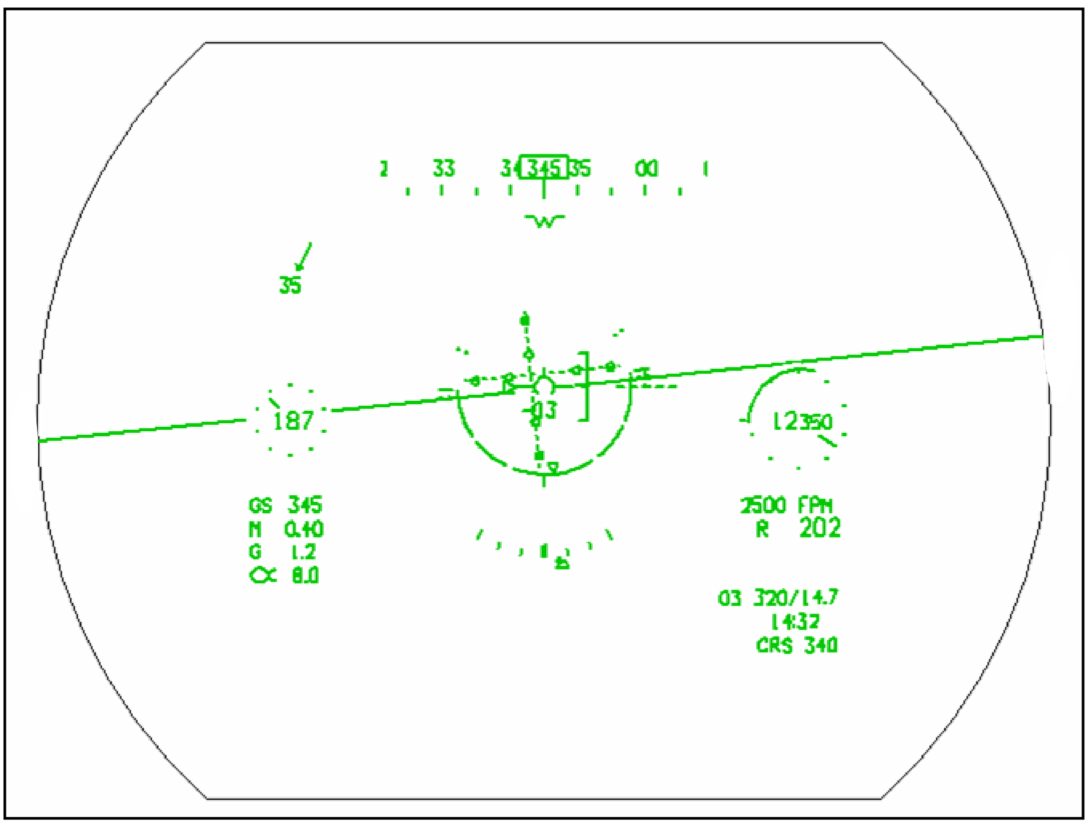


Figure 28 Arc Segment Attitude Reference Head-Up Display Symbology for ILS Precision Approach

HUD Acceptability, Workload, and SA.

Head-up display acceptability, workload, and situation awareness were measured while maintaining AOA, glide slope, and course within preset bounds during an ILS precision approach (reference 6).

Pilot Performance Rating.

The desired and adequate performance ratings were counted for course, glideslope, and AOA from the target performance criteria specified in table 5 during the precision ILS approach.

Table 5 ILS Approach Evaluation Criteria

Maneuver	Event	Rating	
		Desired (95% of the time during task)	Adequate (90% of the time during task)
Instrument Approach	- Established in holding - Arc from holding, partial configuration on arc, 1,500 feet MSL/190 KIAS - Intercept final approach course, maintain altitude, slow to 11° AOA - at FAF, final configuration to DH, 3° GS/11° AOA	Precision Course ±1 dot GS ±1 dot AOA ±1°	Precision Course ±1.5 dot GS ±1.5 dot AOA ±2°

Notes:
1. AOA - angle of attack
2. FAF - final approach fix
3. DH - decision height
4. GS - groundspeed

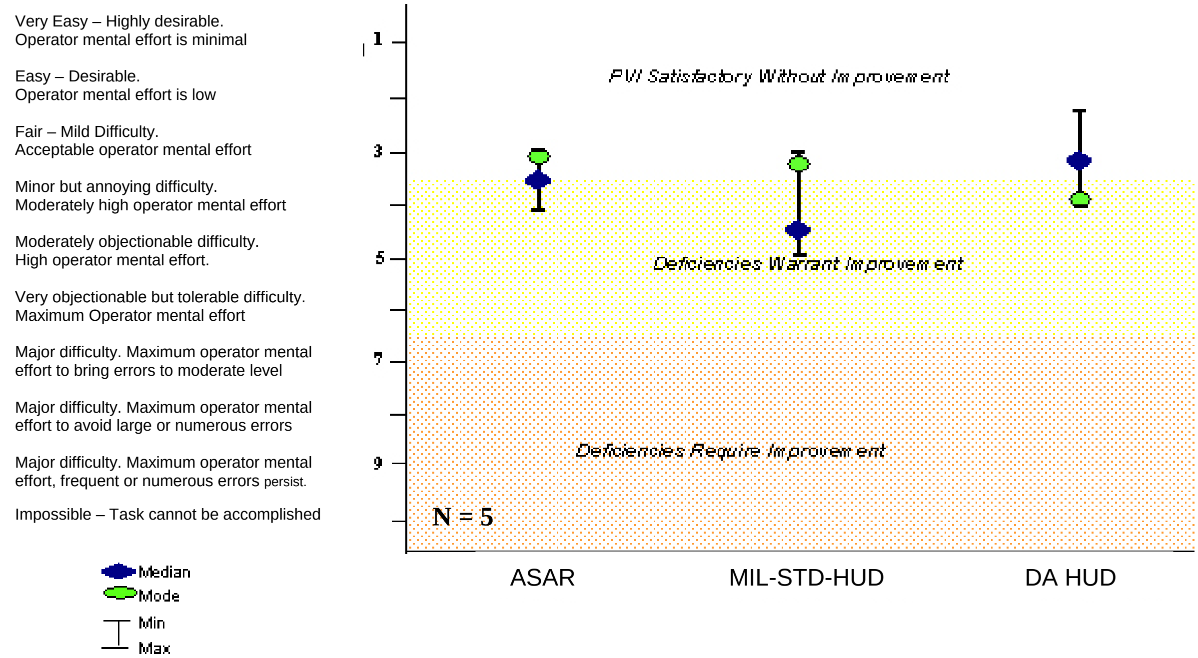
Task performance measurement (Desired/Adequate Criteria) began at the final approach fix point (phase C of figure 27) when within one dot of zero deviation in glide slope. Task performance measurement ended at the decision height (phase D of figure 27), 200 feet.

Test Results:

HUD Acceptability, Workload, and SA.

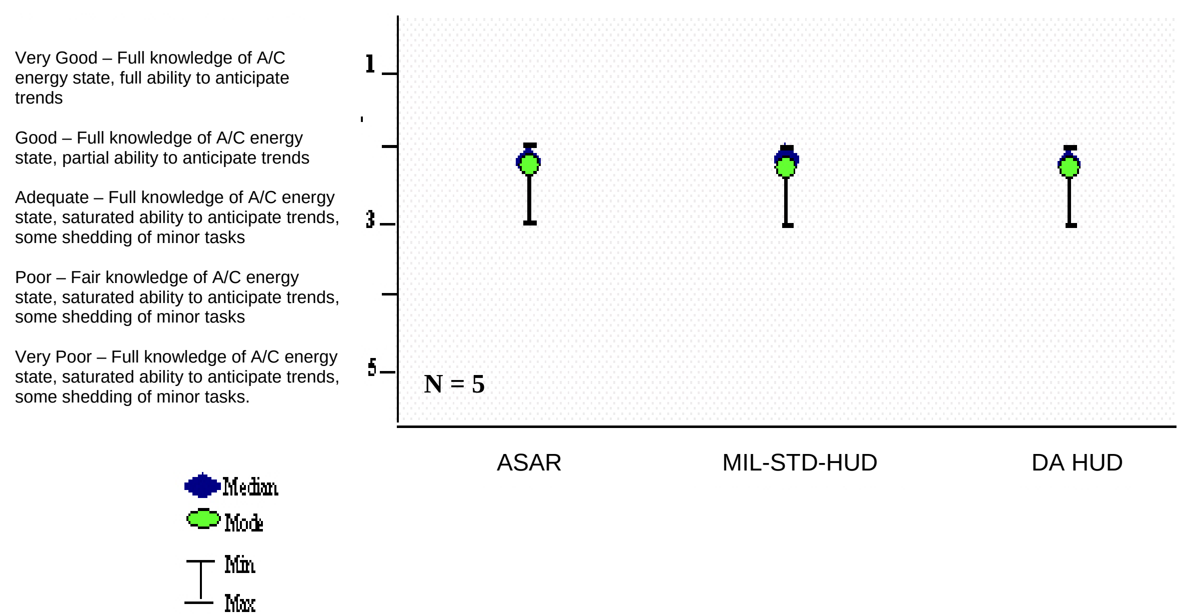
All three HUD formats were satisfactory for performing ILS approaches. Median HUD acceptability ratings were satisfactory for all three HUD formats. However, both the ASAR and DA HUD workload were borderline between satisfactory and marginal. The MIL-STD 1787C HUD workload was marginal (figure 29). Situation awareness for all three HUD formats was satisfactory (figure 30).

The ASAR HUD was cluttered in the vicinity of the ILS needles, which resulted in a noticeable course deviation before the pilot noticed the discrepancy and made a correction. Since there was a negligible crosswind, the vertical velocity indicator and CDM symbology were co-located on the HUD with the ILS needles. This resulted in occlusion of the intersection of the ILS needles, which hindered precise course control. This resulted in a 'sloppy approach.' The single-digit FPA did not provide optimum gradation, that is, the actual glideslope was 2.5, but the indication showed a 2 or 3. An analog odometer-type display may allow more precise course control. Two pilots commented that incorporating the odometer FPA display into the ASAR HUD format would definitely result in a superior PFR for ILS approaches. **The ASAR HUD symbology should be improved to provide more attitude awareness and precise aircraft control when within ±10 degrees of the horizon. (R1)**



Notes: 1. ASAR – arc segment attitude reference 3. DA – dual articulated
2. HUD – head-up display

Figure 29 ILS Modified Cooper-Harper Workload Ratings by Head-Up Display Format



Notes: 1. ASAR – arc segment attitude reference 3. DA – dual articulated
2. HUD – head-up display

Figure 30 ILS China Lake Situation Awareness Ratings by Head-Up Display Format

Pilot Performance Rating.

The pilot performance ratings for all three HUD formats were in the desired range (figure 31). The ASAR HUD symbology had the most desired performance outcomes with the fewest unsatisfactory outcome ratings compared to the DA and MIL-STD-1787C HUD formats.

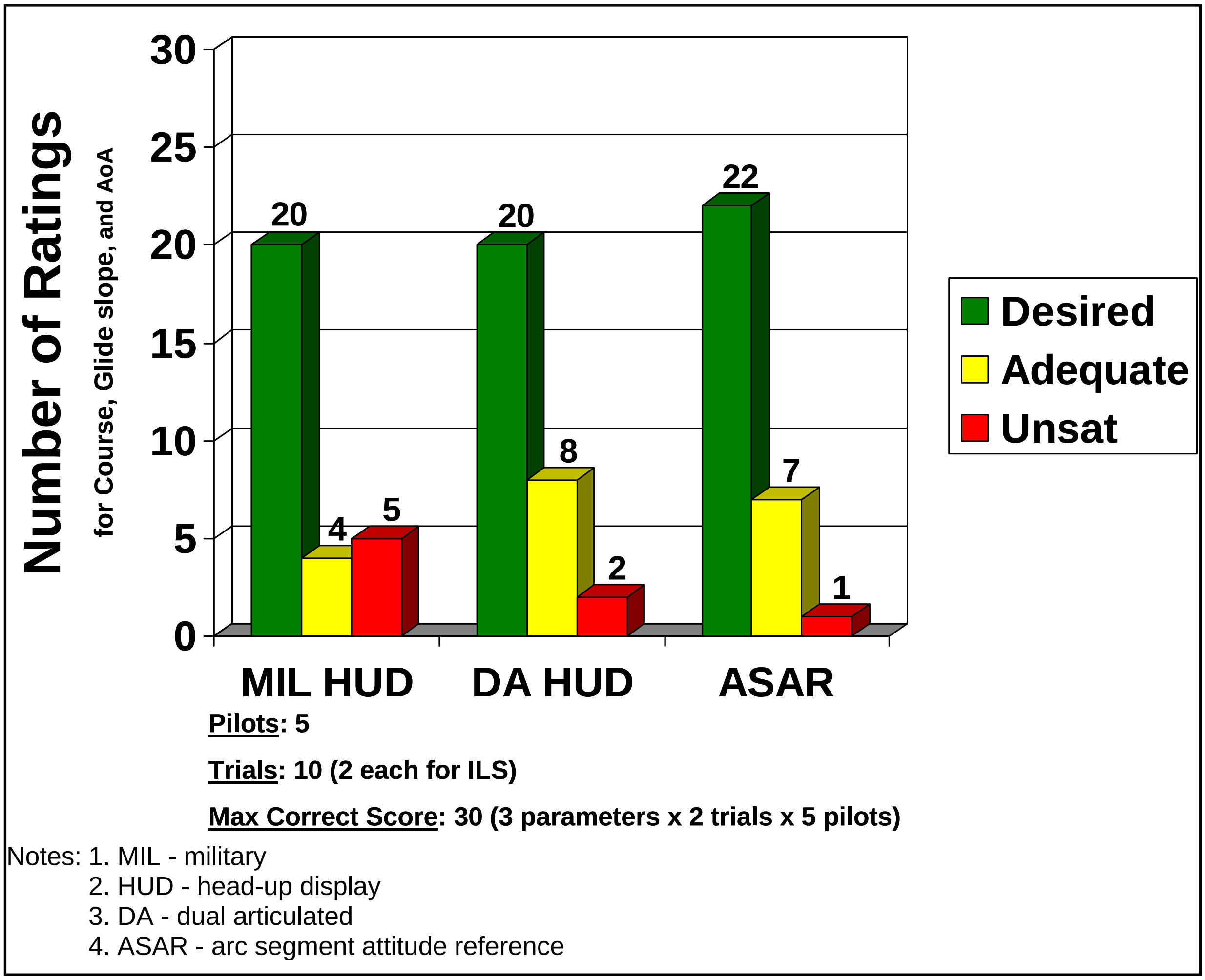


Figure 31 Performance Ratings for ILS Precision Approach Task

An area of interest during this evaluation was the potential for clutter when the ASAR was incorporated in a HUD. The most cluttered condition during testing was the precision ILS maneuver. The ASAR did somewhat reduce the amount of symbology in the HUD without degrading performance. Follow-on testing with tactical mission and carrier landing symbology would be beneficial to further evaluate the suitability and military utility of the ASAR when used with various HMD formats. **Test the ASAR HUD further to determine its effectiveness as a primary flight reference when used with mission/tactical symbology. (R2)**

Further testing could also investigate the effectiveness of the ASAR when used with a HMD as an off-boresight, or off-axis, attitude reference. Although the MIL-STD-1787C climb dive ladder was suitable for use as an attitude reference on a HMD visor when the pilot was viewing on-axis, it was unsuitable for off-axis use. A suitable HMD off-axis attitude reference was a requirement if an HMD was to be endorsed as a PFR. The ASAR may prove satisfactory as an attitude reference for both on- and off-axis viewing. **Test the ASAR HUD further to determine its suitability as an attitude reference for both on-axis and off-axis viewing using a helmet mounted display. (R3)**

MILITARY UTILITY

Helmet-Mounted Display Symbology:

Helmet mounted displays (HMDs) were initially developed to enhance the warfighter's ability to locate, track and engage targets. This was successfully accomplished in the F-15 and F-16 aircraft using the joint helmet mounted cueing system (JHMCS). However, the JHMCS symbology provided only targeting information. It did not display aircraft system parameters or navigation information. Consequently, it was necessary to use the JHMCS in conjunction with a fixed HUD, a combiner glass mounted on the cockpit glareshield panel in the pilot's forward line of sight. The HUD provided system and navigation information and was endorsed as a PFR—a display essential for aircraft control.

With the rapid development of HMD technology, the focus shifted to developing symbology that would enable the HMD to replace the stationary HUD and also be endorsed as a PFR. The key challenge was to ensure the HMD symbology could be used for on- and off-boresight maneuvering. The results of the testing documented in this report indicated that the ASAR symbology format was satisfactory for on-boresight aircraft maneuvering. Previous flight tests with the ASAR have concluded that off-boresight use in a HMD provided better performance for aircraft combat maneuvering than when using the on-boresight HUD alone. The current test results demonstrated that the ASAR symbology reduced clutter, enhanced the warfighter's ability to maintain attitude awareness and spatial orientation, and aided in the recovery from unusual attitudes.

This page intentionally left blank.

.

CONCLUSIONS AND RECOMMENDATIONS

Three head-up display (HUD) formats were evaluated: the arc segment attitude reference (ASAR), dual articulated (DA), and MIL-STD-1787C. The intent was to isolate differences in pilot task performance due to differences in the attitude format presented on the HUD. All HUD symbology was kept the same across the three formats except for the attitude indication. Pilot reaction time during unusual attitude recovery (UAR) tasks using the ASAR HUD was statistically significantly faster than when using the MIL-STD-1787C HUD. However, it was not significantly different for the ASAR HUD in comparison with the DA HUD. All three HUD formats were satisfactory for performing vertical banked S-turn (S-B) and vertical dive S-turn maneuvers, and ILS approaches. The ASAR HUD was the format most preferred for completion of the nose-low UAR task.

However, during the S-B maneuvers, precise vertical velocity control was difficult to maintain due to the limited ability to discern small deviations in pitch attitude from the ASAR format. This resulted in continuous oscillations in vertical velocity and undesirable flightpath angle (FPA) deviations any time the pilot's airspeed scan exceeded one second. One solution may be an analog FPA indication ("odometer-type") that would provide a more precise indication of FPA, and also quickly and clearly indicate rate trends.

> ***The ASAR HUD symbology should be improved to provide more attitude awareness and precise aircraft control when within ±10 degrees of the horizon. (R1, page 18, 19, 25, and 29)***

The ASAR HUD was developed as an alternative symbology format for use in the design of an improved primary flight reference (PFR). Follow-on testing with tactical mission and carrier landing symbology would be beneficial to evaluate the military utility of the ASAR as a PFR.

> ***Test the ASAR HUD further to determine its effectiveness as a primary flight reference when used with mission/tactical symbology. (R2, page 30)***

Further testing could also investigate the effectiveness of the ASAR when used with a helmet mounted display (HMD) as an off-boresight, or off-axis, attitude reference. Although the climb dive ladder was suitable for use as an on-axis attitude reference on an HMD, it was unsuitable for off-axis use. An off-axis attitude reference was a requirement if an HMD was to be endorsed as a PFR. The ASAR may prove satisfactory as an attitude reference for both on- and off-axis viewing.

> ***Test the ASAR HUD further to determine its suitability as an attitude reference for both on-axis and off-axis viewing using a helmet-mounted display. (R3, page 31)***

This page intentionally left blank

REFERENCES

1. Department of Defense Interface Standard, *Aircraft Display Symbology*, MIL-STD-1787C, U.S. Department of Defense, Defense Automated Printing Service, Philadelphia, Pennsylvania, 2000.

2. Fischer, G. and Fuchs, W., “Symbology for Head-Up and Head-Down Applications for Highly Agile Fighter Aircraft – to Improve Spatial Awareness,” presented at the Advisory Group for Aerospace Research and Development (AGARD) Symposium on Combat Automation of Airborne Weapon Systems Man/Machine Interface: Trends and Technologies. AGARD-CP-520, Edinburgh, Scotland, 19-22 October 1992.

3. Fuchs, W., and Fischer, G., “Arc Segment Attitude Reference – ASAR,” presented at the AGARD Symposium on Flight Simulation: Where are the challenges? AGARD-CP-577, Edinburgh, Scotland, May 1995.

4. Wierwille, W. W. and Casali, J. G., “A Validated Rating Scale for Global Mental Workload Measurement Applications,” presented at the Human Factors Society 27th Annual Meeting. Human Factors Society, Santa Monica, California, 1983.

5. Adams, S. R., “Practical Considerations for Measuring Situational Awareness,” presented at the 3rd Annual Symposium on Situational Awareness in the Tactical Environment, Patuxent River, Maryland, 1998.

6. Air Force Manual 11-217, *Instrument Flight Procedures,* U.S. Department of the Air Force, Headquarters USAF, Washington DC, 1996.

7. Jenkins, Joseph C., *Arc Segment Attitude Reference Head-Up Display Symbology as a Primary Flight Reference*, Air Force Flight Test Center, AFFTC-TP-04-13, 21 June 2004.

8. WI-FRG-NF-16D-0064-R05, *VISTA/F-16 VSS Pilot’s Operating Manual*, Calspan Corporation Flight Research Group, Buffalo, New York, September 12, 2001.

9. Babbitt, B.A. and Nystrom, C.O., *Questionnaire Construction Manual*, U.S. Army Research Institute for the Behavioral and Social Sciences, Fort Hood, Texas, 1989.

10. *NIST/SEMATECH e-Handbook of Statistical Methods*, http://www.itl.nist.gov/div898/handbook/, accessed 18 August 2006.

This page intentionally left blank.

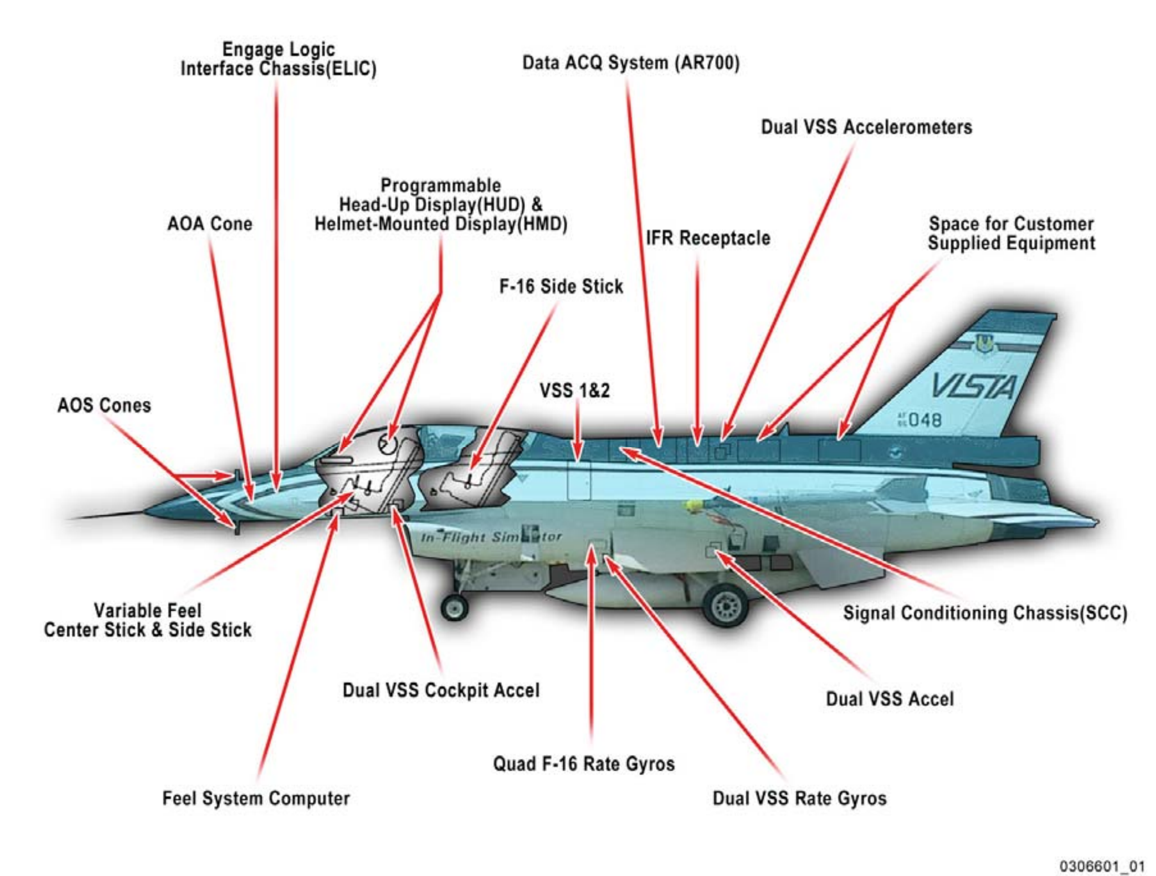
APPENDIX A - VISTA DESCRIPTION

VARIABLE-STABILITY IN-FLIGHT SIMULATOR TEST AIRCRAFT (VISTA) NF-16D

The USAF NF-16D VISTA, serial number 86-0048 was a modified F-16D Block 30, Peace Marble II (Israeli version) aircraft with a digital flight control system using Block 40 avionics and powered by an F100-PW-100B engine. To allow the pilot in command or safety pilot (SP) to fly from the aft cockpit, all necessary controls were moved from the front to the aft cockpit. The aft cockpit had conventional F-16 controls except the throttle was driven by a servo, which followed electrical commands from the front cockpit when the VISTA Simulation System (VSS) was engaged. Primary VSS controls, displays, and system engagement were located in the aft cockpit. The front cockpit included the VSS control panel needed to engage the variable feel center stick or sidestick, but the VSS could only be engaged from the aft cockpit. Front cockpit multifunction displays (MFDs) also mirrored the aft cockpit MFDs and could be used for simulation configuration controls if necessary. Other modifications to the aircraft included a higher flow rate hydraulic system with increased capacity pumps and higher rate actuators, as well as modifications to electrical and avionics systems required to support VSS operations. The layout of major components in the VISTA F-16 is shown in figure A1.

The test points were flown from the front cockpit using the sidestick controller. Test points were flown in either the VSS or NF-16D VISTA operating modes. The rear cockpit SP set up the VSS computer and the head-up display (HUD) configurations, performed routine F-16 flight procedures, and monitored the safety of the evaluations. At any time, the SP could disengage the VSS and take control of the aircraft.

The Calspan Corporation, Buffalo, New York (formerly General Dynamics Advanced Information Systems Group) developed VISTA software to implement the test maneuvers described in AFFTC-TP-04-13, *Arc Segment Attitude Reference Head-up Display Symbology* (reference 7). The VISTA instrumentation system was set up to aid in timing, measuring, calculating, displaying, and recording test events, as well as adequate and desired performance.



Notes:
1. ACQ - acquisition
2. VSS - Variable-Stability In-Flight Simulator Test Aircraft Simulation System
3. AOA - angle of attack
4. AOS - angle of sideslip

Extracted from WI-FRG-NF-16D-0064-R05, *VISTA/F-16 VSS Pilot's Operating Manual*, (reference 8)

Figure A1 Variable In-Flight Simulator Test Aircraft Component Layout

VISTA SIMULATION SYSTEM

The VSS consisted of three flight-qualified digital computers that interfaced with the F-16 digital flight control system, associated sensors, signal conditioners, and displays. For in-flight simulation, the VISTA used an implicit model-following technique where the aerodynamic model and VSS feedback gains were used to model unaugmented response characteristics. The VSS computers also hosted flight control laws, which allowed the VISTA to generate closed loop response characteristics. The fully programmable variable feel system of the VISTA could model nonlinearities such as breakout, friction, soft-stops, hard-stops, and multiple stick gradients, and adjust stick frequency and damping. The VISTA had the capability to change stick characteristics and selected flight control gains during the course of a flight using either MFDs or stored programs. However, only those gains and characteristics which had been previously ground simulated on the VISTA and verified to properly operate were tested in flight. The VSS also included built-in test functions, software safety trips, safety trip reporting, engage and disengage logic, and VISTA vehicle integrity monitor logic. The VISTA flight control modes were:

1. DISENGAGED MODE: The SP in the aft cockpit was in control of the aircraft and his inputs were processed through the standard F-16 digital flight control laws. The VSS was out of the loop. This mode was the default on powerup and could be entered directly from any other mode.

2. F-16 MODE: The pilot in the front cockpit was in control of the aircraft and his inputs were processed through the standard F-16 digital flight control laws. The F-16 Mode was entered from the Disengaged Mode and returned to the Disengaged Mode if any of the safety trips were activated.

3. F-16 EMERGENCY MODE: The pilot in the front cockpit was in control of the aircraft and his inputs were processed through the standard F-16 digital flight control laws. The Emergency Mode could be entered from any mode but was only used if the SP was incapacitated or the aft cockpit controls were malfunctioning. If the pilot deselected the Emergency Mode, the aircraft reverted to the F-16 Mode. If the SP deselected the Emergency Mode, the aircraft reverted to the Disengaged Mode.

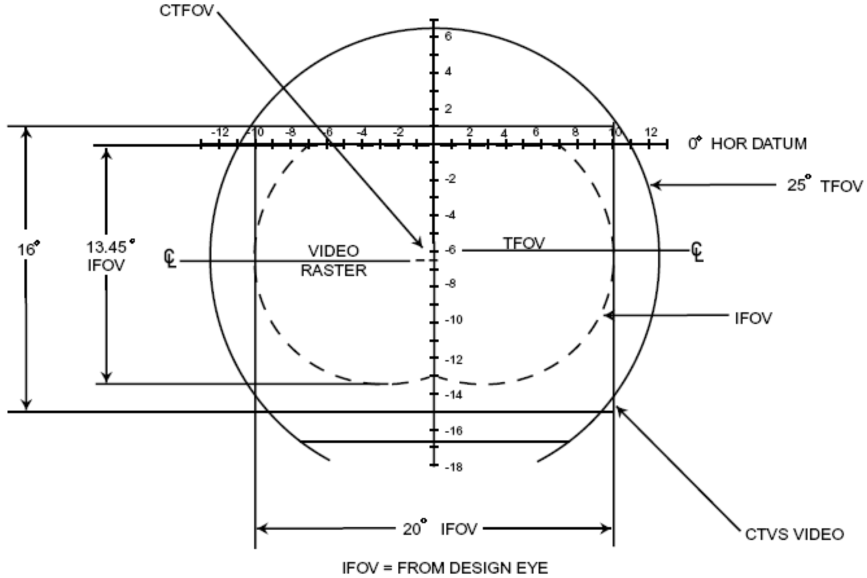
4. VSS MODE: The pilot in the front cockpit was in control of the aircraft and his inputs were processed through VSS using the simulated control laws and aerodynamics. The VSS Mode was entered from the Disengaged Mode and returned to Disengaged Mode if any of the safety trips were activated.

VISTA Display System:

For this testing, the VISTA programmable HUD was the primary display for the pilot occupying the front cockpit. The VISTA F-16 HUD had an instantaneous field-of-view of 20 degrees by 13.45 degrees (figure A2).

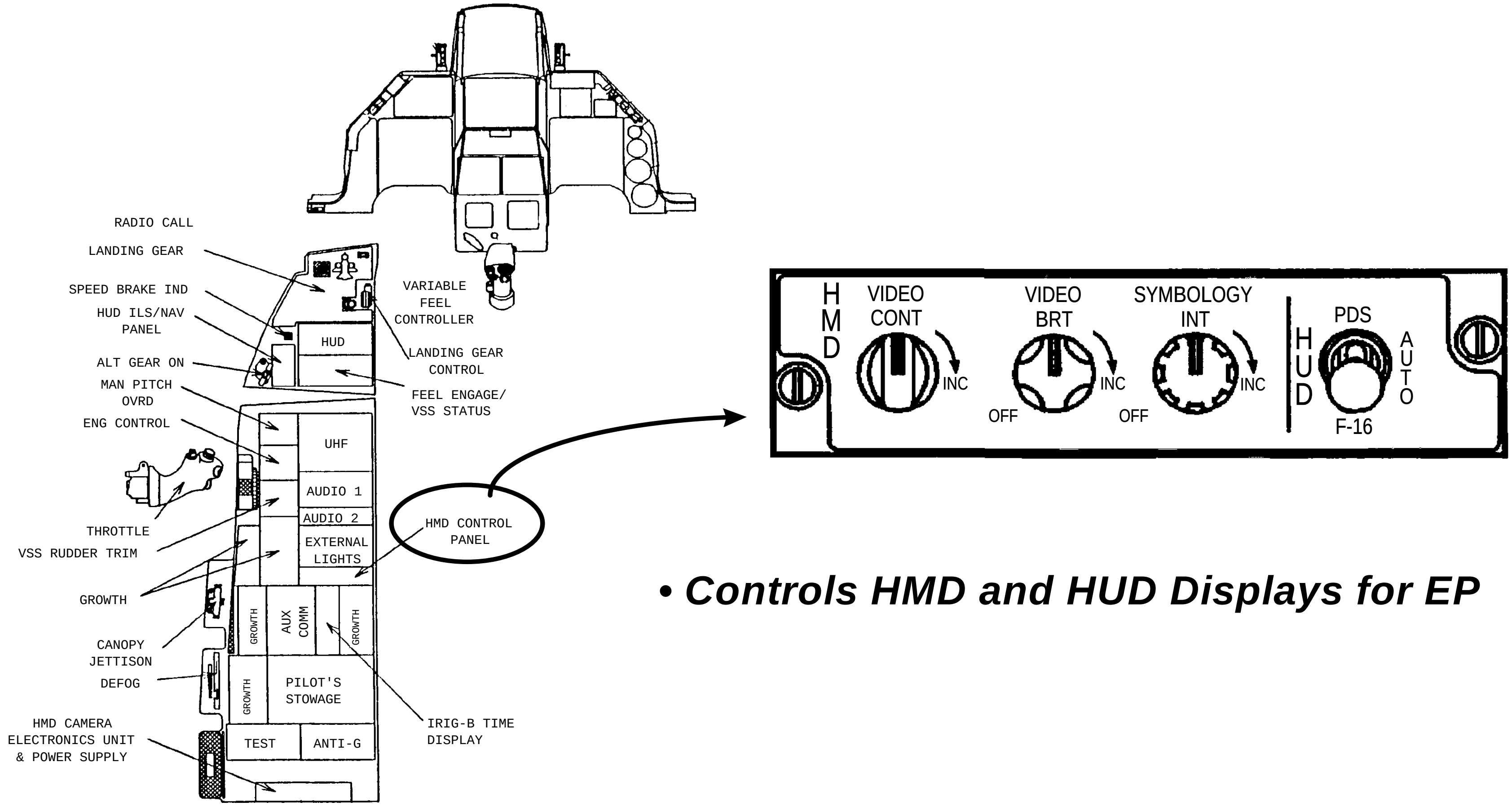
The front seat HUD pilot display unit displayed either the nominal F-16 HUD or the programmed HUD display from the programmable display unit (PDS) (i.e., the PDS HUD). The display selection was activated by the HUD electronics unit switching unit. Head-up display electronics unit switching unit selection was controlled by a switch in the front cockpit, located on the HUD control panel (figure A3). From the HUD Selector, HUD (forward switch position – ‘PDS’) could be selected manually or the selection could be made by VSS computer control (center position – ‘AUTO’).

The rear cockpit, occupied by the SP, was essentially unaffected by the PDS with the notable exception that the PDS power switch was on the avionics power panel in the rear cockpit (on the non-essential avionics bus) and video switches had been added so the SP could, at any time, view the same displays as the pilot on either the right MFD or aft seat HUD monitor. The pilot could also view the nominal F-16 HUD on either the aft seat HUD monitor or right MFD at any time, in addition to the PDS HUD.



Notes:
1. CTFOV - central total field-of-view
2. IFOV - instantaneous field-of-view
3. TFOV - total field-of-view

Figure A2 Variable In-Flight Simulator Test Aircraft NF-16D Head-Up Display 20 by 13.45 Degrees Instantaneous Field of View



Notes:

1. HUD - head-up display
2. NAV - navigation
3. ALT - altitude
4. INC - increment
5. COMM - communication
6. CONT - control
7. MAN - manual
8. OVRD - override
9. ENG - engine
10. BRT - brightness
11. INT - internal
12. AUX - auxiliary
13. VSS - Variable-Stability In-Flight Simulator Test Aircraft Simulation System
14. PDS - programmable display system
15. IRIG - Inter-Range Instrumentation Group
16. HMD - helmet-mounted display

Figure A3 Variable In-Flight Simulator Test Aircraft NF-16D HUD Control Panel

This page intentionally left blank.

APPENDIX B – RATING SCALES, RATING SCALE DATA AND PILOT RATINGS

The China Lake Situation Awareness rating scale, table B1, and Modified Cooper-Harper workload scale, figure B1, served as the two principal means by which pilot performance was assessed outside of objective performance measures. In addition to pilot workload and situation awareness ratings, a head-up display (HUD) acceptability questionnaire was completed following each piloting task. These rating scales and questionnaires are provided in this appendix as a reference to each subjective measure of performance.

Figure B2 shows the acceptability rating scale extracted from *Questionnaire Construction Manual*, reference 9. Table B2 (reference 5) contains pilot system adequacy ratings for each HUD type (arc segment attitude reference [ASAR] dual-articulated [DA], and MIL-STD) for each piloting task.

Table B1 China Lake Situation Awareness Rating Scale

Situation Awareness Scale Value	Content
Very Good – 1	• Full knowledge of A/C energy state / tactical environment / mission • Full ability to anticipate / accommodate trends
Good – 2	• Full knowledge of A/C energy state / tactical environment / mission • Partial ability to anticipate / accommodate trends
Adequate – 3	• Full knowledge of A/C energy state / tactical environment / mission • Saturated ability to anticipate / accommodate trends • Some shedding of minor tasks
Poor – 4	• Fair knowledge of A/C energy state / tactical environment / mission • Saturated ability to anticipate / accommodate trends • Shedding of all minor tasks as well as many not essential to flight safety / mission effectiveness
Very Poor – 5	• Minimal knowledge of A/C energy state / tactical environment / mission • Oversaturated ability to anticipate / accommodate trends • Shedding of all tasks not absolutely essential to flight safety / mission effectiveness

Note: A/C – aircraft

Scale extracted from reference 5.

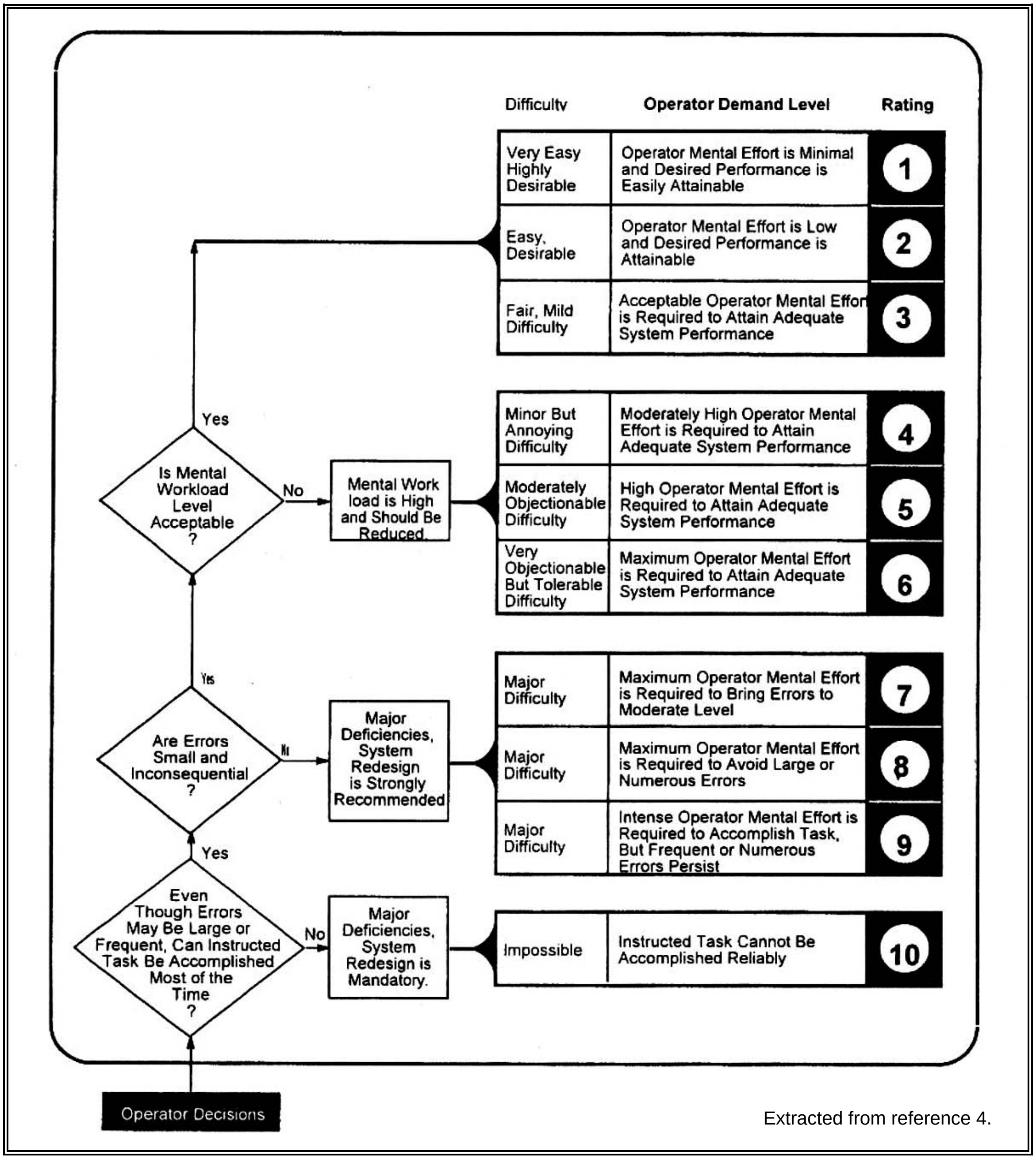


Figure B1 Modified Cooper-Harper Workload Rating Scale

Rating	Description
Very Satisfactory	Only provide comments on PFR elements/features you particularly liked (Very satisfactory, I particularly liked….).
Satisfactory	Good ideas (including from legacy aircraft); Nice to have changes; Not essential but in your opinion would enhance the PFR (Satisfactory, A nice to have/good idea might be….).
Marginally Satisfactory	PFR can be used as is, but changes would improve the PFR (It's satisfactory, but could be improved by….).
Marginally Unsatisfactory	Minor changes necessary to make the PFR usable (Marginally unsatisfactory, minor improvements are….).
Unsatisfactory	Major to minor changes necessary to make PFR usable. PFR deficient (Unsatisfactory, required improvements are….)
Very Unsatisfactory	Major changes necessary to make PFR usable (Unsatisfactory, mandatory improvements are….).
Not Applicable	No Rating (No rating provided because….).

Note: PFR - primary flight reference

Extracted from reference 9

Figure B2 Head-Up Display Acceptability Rating Scale for Questionnaire

ASAR HUD Questionnaire:

1. Unusual Attitude Recoveries (UARs) Task

Please rate the acceptability of the ASAR HUD to recover from an unusual attitude.

Very Satisfactory	Satisfactory	Marginally Satisfactory	Marginally Unsatisfactory	Unsatisfactory	Very Unsatisfactory	Not Applicable
Comments:						

2. Basic Flight – Approach Task

Please rate the acceptability of the ASAR HUD to fly a precision approach.

Very Satisfactory	Satisfactory	Marginally Satisfactory	Marginally Unsatisfactory	Unsatisfactory	Very Unsatisfactory	Not Applicable
Comments:						

3. Vertical S

Please rate the acceptability of the ASAR HUD to fly a Vertical S-B maneuver.

Very Satisfactory	Satisfactory	Marginally Satisfactory	Marginally Unsatisfactory	Unsatisfactory	Very Unsatisfactory	Not Applicable
Comments:						

Please rate the acceptability of the ASAR HUD to fly a Vertical S-D maneuver.

Very Satisfactory	Satisfactory	Marginally Satisfactory	Marginally Unsatisfactory	Unsatisfactory	Very Unsatisfactory	Not Applicable
Comments:						

4. Any additional comments on the ASAR HUD as a primary flight reference (PFR)?

5. Any other comments?

DA HUD Questionnaire:

1. UAR Task

Please rate the acceptability of the DA HUD to recover from an unusual attitude.

Very Satisfactory	Satisfactory	Marginally Satisfactory	Marginally Unsatisfactory	Unsatisfactory	Very Unsatisfactory	Not Applicable
Comments:						

2. Basic Flight – Approach Task

Please rate the acceptability of the DA HUD to fly a precision approach.

Very Satisfactory	Satisfactory	Marginally Satisfactory	Marginally Unsatisfactory	Unsatisfactory	Very Unsatisfactory	Not Applicable
Comments:						

3. Vertical S

Please rate the acceptability of the DA HUD to fly a Vertical S-B maneuver.

Very Satisfactory	Satisfactory	Marginally Satisfactory	Marginally Unsatisfactory	Unsatisfactory	Very Unsatisfactory	Not Applicable
Comments:						

Please rate the acceptability of the DA HUD to fly a Vertical S-D maneuver.

Very Satisfactory	Satisfactory	Marginally Satisfactory	Marginally Unsatisfactory	Unsatisfactory	Very Unsatisfactory	Not Applicable
Comments:						

4. Any additional comments on the DA HUD as a PFR?

5. Any other comments?

MIL-STD-1787C HUD Questionnaire:

1. UAR Task

Please rate the acceptability of the MIL-STD-1787C HUD to recover from an unusual attitude.

Very Satisfactory	Satisfactory	Marginally Satisfactory	Marginally Unsatisfactory	Unsatisfactory	Very Unsatisfactory	Not Applicable
Comments:						

2. Basic Flight – Approach Task

Please rate the acceptability of the MIL-STD-1787C HUD to fly a precision approach.

Very Satisfactory	Satisfactory	Marginally Satisfactory	Marginally Unsatisfactory	Unsatisfactory	Very Unsatisfactory	Not Applicable
Comments:						

3. Vertical S

Please rate the acceptability of the MIL-STD-1787C HUD to fly a Vertical S-B maneuver.

Very Satisfactory	Satisfactory	Marginally Satisfactory	Marginally Unsatisfactory	Unsatisfactory	Very Unsatisfactory	Not Applicable
Comments:						

Please rate the acceptability of the MIL-STD-1787C HUD to fly a Vertical S-D maneuver.

Very Satisfactory	Satisfactory	Marginally Satisfactory	Marginally Unsatisfactory	Unsatisfactory	Very Unsatisfactory	Not Applicable
Comments:						

4. Any additional comments on the MIL-STD-1787C HUD as a PFR?

5. Any other comments?

Table B2 Head-Up Display (HUD) Acceptability Ratings Data

Pilot	Task	Arc Segment Attitude Reference HUD	Dual Articulated HUD	MIL-STD HUD
4	Unusual attitude recovery (UAR)	5.0	5.0	5.0
	Approach	4.0	4.0	4.0
	Vertical Banked S-Turn (S-B)	5.0	5.0	5.0
	Vertical Dive S-Turn (S-D)	5.0	5.0	5.0
3	UAR	5.0	5.0	5.0
	Approach	5.0	5.0	5.0
	Vertical S-B	5.0	5.0	5.0
	Vertical S-D	5.0	5.0	5.0
1	UAR	6.0	5.0	3.0
	Approach	4.0	5.0	5.0
	Vertical S-B	4.0	4.0	4.0
	Vertical S-D	4.0	4.0	4.0
2	UAR	6.0	5.0	4.0
	Approach	5.0	5.0	5.0
	Vertical S-B	4.0	4.0	4.0
	Vertical S-D	4.0	4.0	4.0
Median	UAR	5.5	5.0	4.5
	Approach	4.5	5.0	5.0
	Vertical S-B	4.5	4.5	4.5
	Vertical S-D	4.5	4.5	4.5

Table B3 Demographic Information for Participating Test Pilots

Pilot	Service	Aircraft Type	Number of Flight Hrs (Sim Hrs)	
1	USMC	F/A-18 AV-8B T-2	1,750 400 150	(200) (50) (30)
2	USN	F/A-18 A-F Other (27)	1000 500	---
3	USMC	F/A-18 A-D	1,750	(200)
4	Lockheed Martin Aeronautics (USAF Retired)	F-15 A/B/C/D F-22 F-16	2,600 260 300	(400) (100) (50)
5	USAF	A-10 F-16 F-15	1,500 900 40	---

This page intentionally left blank.

APPENDIX C – TEST DESIGN AND ANALYSIS

A 3 (display) x 2 (attitude) repeated measures analysis-of-variance (ANOVA) was performed using the Statistical Package for the Social Sciences (SPSS v.14) software to determine if there were statistically significant differences between UAR initial stick input reaction times for the three HUD formats. The alpha level for the ANOVA was set at $\alpha = .05$ and the Greenhouse-Gesser correction for sphericity was used to obtain degrees-of-freedom and associated test criterion probability values. The mean initial stick input reaction times for each of the three HUD formats were found to be statistically significantly different from each other (significant main effect). The *F* statistic for 2 and 50 degrees of freedom was equal to 3.92. The statistical probability of these mean differences occurring due to chance was computed to equal 0.038. A post-hoc statistical analysis of the means data using the Bonferroni method (*NIST/SEMATECH e-Handbook of Statistical Methods*, reference 10) to correct for multiple comparisons revealed that reaction time with the ASAR HUD was statistically significantly faster than that of the MIL-STD-1787C HUD symbology ($p < .05$, see figure 16). The differences in reaction time for the DA HUD and MIL-STD-HUD ($p = .07$) were not statistically significant. The ANOVA conducted on the correctness of pilot control inputs data for the UARs showed that there was no statistically significant difference in correctness of control input between the ASAR HUD format alone and the DA HUD and MIL-STD-1787C HUD formats (see figure 16). Further statistical analyses (ANOVA and Bonferroni method) showed that the difference between initial stick input reaction times for dive UARs (Mean = 1.15 seconds) and climb UARs (Mean = 1.38 seconds) was statistically significant. The *F* probability statistic with 1 and 25 degrees of freedom was equal to 9.25. The statistical probability of these mean differences occurring due to chance was computed to equal 0.005. There were no statistically significant interactions between the reaction time means of the factorial combination of three HUD formats and the two UAR types (climb and dive).

Table C1 Presentation Order of UAR Initial Conditions by Pilot and Symbology

		Unusual Attitude							
Pilot	Symbology	UAR 1	UAR 2	UAR 3	UAR 4	UAR 5	UAR 6	UAR 7	UAR 8
Pilot 1	MIL-HUD 1st	2	8	7	4	6	3	5	1
	DA HUD 2nd	5	7	1	8	4	6	3	2
	ASAR HUD 3rd	3	4	2	1	7	5	6	8
Pilot 2	DA HUD 1st	1	5	2	3	8	7	4	6
	ASAR HUD 2nd	1	6	4	8	3	2	5	7
	MIL-HUD 3rd	8	5	7	4	6	3	1	2
Pilot 3	ASAR HUD 1st	2	6	5	4	3	7	1	8
	MIL-HUD 2nd	4	6	1	3	7	2	5	8
	DA HUD 3rd	4	8	3	1	7	6	5	2
Pilot 4	MIL-HUD 1st	6	8	5	4	2	3	7	1
	DA HUD 2nd	3	4	1	6	8	2	7	5
	ASAR HUD 3rd	4	6	1	3	8	2	5	7
Pilot 5	DA HUD 1st	1	5	3	6	4	7	8	2
	ASAR HUD 2nd	2	3	6	4	8	1	7	5
	MIL-HUD 3rd	8	6	5	7	1	2	4	3

Notes:
1. UAR - unusual attitude recovery
2. MIL - military
3. HUD - head-up display
4. DA - dual articulated
5. ASAR - arc segment attitude reference

This page intentionally left blank.

APPENDIX D - LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

Abbreviation	Definition	Units
A/C	aircraft	---
AFB	Air Force Base	---
AFM	Air Force Manual	---
AFRL	Air Force Research Laboratory	---
AGARD	Advisory Group for Aerospace Research and Development	---
ALT	altitude	---
ANOVA	analysis-of-variance	---
AOA	angle of attack	deg
AOB	angle of bank	deg
AOS	angle of sideslip	deg
ASAR	arc segment attitude reference	---
AUX	auxiliary	---
BRT	brightness	---
CDM	climb/dive marker	---
CLSA	China Lake Situation Awareness	---
COMM	communication	---
CONT	control	---
CTFOV	central total field of view	---
DA	dual articulated	---
deg	degree	---
DH	decision height	---
DOD	Department of Defense	---
ENG	engine	---
FAF	final approach fix	---

LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS (Continued)

Abbreviation	Definition	Units
FPA	flightpath angle	---
fpm	feet per minute	---
FPM	flight path marker	---
ft	feet	---
g	acceleration due to gravity	32.2 fps^2
GS	groundspeed	---
HMD	helmet-mounted display	---
HUD	head-up display	---
IAF	instrument approach fix	---
IAW	in accordance with	---
IFOV	instantaneous field of view	---
ILS	instrument landing system	---
IMC	instrument meteorological conditions	---
INC	increment	---
INT	internal	---
IRIG	Inter-Range Instrumentation Group	---
K	thousand	---
KIAS	knots indicated airspeed	---
MAN	manual	---
MCH	Modified Cooper-Harper	---
MFD	multifunction display	---
MIL	military	---
MIL-STD	military standard	---
MSL	mean sea level	---
NAV	navigation	---

LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS (Concluded)

Abbreviation	Definition	Units
No.	number	---
OVRD	override	---
p	statistical probability value	---
PDS	programmable display system	---
PFR	primary flight reference	---
RT	reaction time	---
S-B	banked S-turn	---
S-D	dive S-turn	---
SA	situation awareness	---
secs	seconds	---
SP	safety pilot	---
TFOV	total field of view	---
TPS	Test Pilot School	---
UAR	unusual attitude recovery	---
USAF	United States Air Force	---
USMC	United States Marine Corp	---
USN	United States Navy	---
VISTA	Variable-Stability In-Flight Simulator Test Aircraft	---
VRD	visual restriction device	---
VSI	vertical situation indicator	---
VSS	VISTA Simulation System	---
VVI	vertical velocity indication	---
$^{\circ}$	degree	---
%	percent	---
α	statistical alpha value	---

This page intentionally left blank.

APPENDIX E - DISTRIBUTION LIST

Offsite Distribution	Number of Copies CD	Number of Copies Paper
Defense Information Systems Agency DTIC 8725 John J Kingman Rd, Ste 0944 Attn: Mary Roth (DTIC/OMP) Fort Belvoir VA 22060-6218	1	0
AFRL/HECV Attn: Dr. Paul Havig 2255 H St Wright-Patterson AFB OH 45433-7022	1	1
Directorate of Airman Development and Sustainment (AF/A1D) Attn: Capt Chris Jenkins 4025 Old Hickory Rd Fairfax VA 22032	1	1
NASIC/ADA 4180 Watson Wy Wright-Patterson AFB OH 45433-5648	1	0
53 TMG/TO Attn: Mr. Pete Strong/Maj Dan Brown 203 West D Ave, Bldg 351 Rm 408 Eglin AFB FL 32542-6867	1	0
53 TEG/CC Attn: Col Neubeck/Mr. Bob Drabant 4410 Tyndall Ave, Bldg 100 Nellis AFB NV 89191	1	0
Onsite Distribution		
AFFTC/HO 305 E Popson Ave, Bldg 1405 Edwards AFB CA 93524-6595	1	1
812 TSS/ENTL 307 E Popson Ave, Bldg 1400, Rm 110 Edwards AFB CA 93524-6630	2	2

APPENDIX E - DISTRIBUTION LIST (Concluded)

Onsite Distribution	Number of Copies CD	Paper
773 TS/ENFH Attn: Deborah A. Moisio 307 E Popson Ave, Bldg 1400, Rm 403 Edwards AFB CA 93524-6630	1	0
412 OG/DT Attn: James Johnson 195 E Popson Ave Edwards AFB CA 93524	1	0
AFFTC/CZ Attn: Dan Roth 1 South Rosamond Blvd, Bldg 1 Edwards AFB CA 93524-1031	0	1
461 FLTS/ENFH Attn: Paul Robinson 225 North Flightline Road Edwards AFB CA 93524-6630	1	0
USAF TPS/CT Attn: John Minor 220 South Wolfe Ave Edwards AFB CA 93524-6485	1	0
Total	13	6